RESEARCH PROGRAM ON Dryland Systems

CGIAR

Nutrient Flow Scenarios for Sustainable Smallholder Farming Systems in South-western Burkina Faso

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Food security and better livelihoods for rural dryland communities

ETH Eidgenössische Technische Hochschule Zürich
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ICARDA Science for Better Livelihoods in Dry Areas

UPB

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The program is led by the International Centre for Agricultural Research in the Dry Areas (ICARDA), a member of the CGIAR Consortium. CGIAR is a global agriculture research partnership for a food secure future.

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List of Acronyms

ALS	Agricultural livelihood system
CRP-DS	CGIAR Research Program on Dryland Systems
ICARDA	International Center for Agricultural Research in Dry Areas
PMU	Program Management Unit
MFA	Material flow analysis
RQ	Research question
SLF	Sustainable Livelihoods Framework
SSM	Soft systems methodology
USYS TdLab	Transdisciplinarity Lab, Department of Environmental Systems Science, ETH Zurich

SECTION I – KEY MESSAGES

a. Summary of Research Progress

The report presents a study on nutrient flows of agricultural livelihood systems dominated by smallholder farms in South-western Burkina Faso. The material flow analysis of nitrogen, phosphorus, and potassium provides a detailed picture of current nutrient flows within, in to, and out of smallholder farms. Such a picture allows quantifying material potentials for sustainable intensification, that is, increasing the ratio of crop yield to mineral fertilizer inputs. Finally, in the pursuit of indicators for sustainable intensification, we propose combining indicators derived from material flow analysis with indicators of socio-economic nature to move from material potential assessments to sustainability assessments. The combination is informed by the criticality concept, a concept which denotes how important a specific material resource is to an anthropogenic system. Based on an existing criticality determination methodology for metals, we sketch the criticality indicator set for the case of nitrogen, phosphorus, and potassium and smallholder farms. Further research should include increasing temporal boundaries to capture cycles longer than a year, the applied temporal boundary in this study. A multi-scale study including villages and landscapes could provide additional insights on the role of water bodies or future .industrial activities in nutrient cycling. In turn, the multi-scale MFAs would provide the necessary indicator values to assess nutrient criticality not only at the smallholder farm level, but also at the village and landscape level. Finally, the material flows could be further characterized with respect to gender, cost/benefits, etc.

b. Significant Research Achievements

The present study demonstrates how one can perform a material flow analysis on smallholder farming systems to inform policies of sustainable intensification from a systems analysis perspective. The study relies on data which are usually anyway collected and on free software for material flow analysis. The significant research achievements of the study are the following:

- Stables and compost heaps are the largest sinks of nitrogen, phosphorus, and potassium in all three agricultural livelihood systems present in the case region. In contrast, the magnitude of flows varies across the three systems and different processes dominate the systems.
- Recycling compost and manure from redistribution to primary production units could significantly reduce negative soil nutrient balances and, at best, totally replace current amounts of mineral fertilizers used. Yet, smallholding farmers seem to lack the necessary knowledge to operate composting facilities and the access to amendments required to activate the composting process is lacking.
- We outline a methodology for the assessment of criticality of nutrients to smallholder farms. The methodology has three dimensions: supply risk, resilience of smallholder farm to supply restriction, and environmental implications. We define components of each dimension and suggest candidate indicators of these components. Using results from the material flow analysis, we demonstrate how indicators of supply risk and resilience to supply restriction can be operationalized.

SECTION II– BACKGROUND, PROBLEMS AND OBJECTIVES

a. Background

Sub-Saharan Africa suffers from chronic food insecurity as a result (among others) of low crop and livestock productivity in agricultural livelihood systems (ALSs) dominated by smallholder farmers. Climate change acts as aggravating factor, as average precipitation amounts decrease and precipitations become less regular (Parry et al. 2009). Smallholder farming hardly allows for a living, so that many farmers are attracted to urban areas and different livelihoods (Djurfeldt and Jirström 2013). The rural exodus threatens the domestic supply of food in African countries whose populations continue to rise (Bezu and Holden 2014).

Sustainable intensification is a strategy to fight chronic food insecurity and make smallholder farming more profitable without threatening the environment. The basic idea of sustainable intensification is to increase crop and livestock yields without increasing land use and by minimizing damages to the natural environment, e.g., energy consumption of mineral fertilizer production (Garnett et al. 2013; Matson et al. 1997; Tilman et al. 2002; Cassman 1999). Farmers can achieve higher yields through improved crop choices and nutrient management. Hence, a prerequisite of sustainable intensification is both the understanding of drivers of nutrient management (including land management) and those of crop choice (Thiombiano and Le 2016b). Also, based on the observed structural and functional heterogeneities of ALSs (Le 2005; Thiombiano and Le 2015; Tittonell et al. 2005), agricultural research has acknowledged the need to tailor policies aiming at sustainable intensification to different ALS types (Le 2005).

b. Research problem

Research on low crop and livestock productivity to inform sustainability intensification potentials and other alleviation strategies focuses on biophysical and socio-economic characteristics of smallholder farms. The focus relies on econometric approaches linking variables with regression analysis and other statistical approaches. The choice of variables is either inductive or informed by theoretical frameworks such as the Sustainable Livelihoods Framework (SLF) (DFID 1999). However, sustainable intensification is a typical sustainability challenge. Not only should intensification not lead to environmental degradation, but there are other goals to be reconciled with intensification, e.g., sustaining rural economies (Garnett et al. 2013). Also, smallholder farms are embedded in broader systems: villages, markets, landscapes which are crucial for their sustainability.

Tackling sustainability challenges requires systems analysis, as understanding linkages within systems, i.e., between processes through flows of materials, information, money, etc., and with their environment/context is crucial for formulating recommendations which allow e.g., avoiding adverse effects such as environmental problem shifting (Venkatesh and Brattebo 2009). Methods for systems analysis are readily available, but their potential in the field of sustainable smallholder farming systems and sustainable intensification has not yet been fully tapped. For instance, flows of organic matter and nutrients between farm processes are studied, however with a focus on the current state and single processes (Briggs and Twomlow 2002; Ncube et al. 2009; Van den Bosch et al. 1998), while the overall system and its potentials are less explored. Additionally, sustainability challenges are best met in transdisciplinary processes, during which valuable context knowledge is integrated with disciplinary knowledge at different stages and for different purposes: joint-problem definition, problem analysis, formulation of recommendations, etc. Besides using best knowledge available and involving affected people, such a functional-dynamic approach of engagement with stakeholders also increases the chances of implementation (Krütli et al. 2010).

The present study consists in the application of systems analysis in a transdisciplinary setting. So far in Pontieba, research has focussed on different elements of ALSs, with the aim of demonstrating the need for tailor-made policies of sustainable intensification. The identification of three ALS types in Pontieba (Thiombiano and Le 2015) set the stage for the identification of determinants of farmers' choices on crops, mineral, and organic uses (Thiombiano and Le 2016a) and the derivation of integrated production functions for main crop fields in Pontieba, i.e., sorghum (millet), groundnuts, rice, maize, cotton (Thiombiano and Le 2016b). However, it remains to be seen how a systems analysis approach can contribute to providing generic and/or ALS-specific recommendations.

b. Research objectives

The goal of this paper is the formulation of generic and/or ALS-specific recommendations for sustainable intensification from a systems analysis perspective. To achieve the goal, three research questions (RQs) are formulated:

1. How do material flows look like in the ALS types in Pontieba?
2. What are material potentials of the ALS types in Pontieba?
3. What are farmer potentials of the ALS types in Pontieba?

Material flow analysis (MFA), a systems analysis method, informs the current material flows, including values of MFA-based indicators, and material potentials for sustainable intensification, i.e., potentials for closed material loops within smallholder farms that allow reducing the needs of external inputs. Here, we focus on the flows and potentials of three nutrients: nitrogen, phosphorus, and potassium. The farmer potentials describe barriers and drivers for farmer action to tap into material potentials. We discuss the material and farmer potentials and provide an outlook on the integration of MFA-based indicators into indicator sets of sustainability assessments. The latter could be of relevance for the development of indicators of sustainable intensification. We conclude with recommendations for policy formulation and future research.

SECTION III – RESEARCH APROACH AND METHODOLOGY

We used two methods, material flow analysis and soft systems methodology, in combination to answer the RQs related to current material flows, material potentials and farmer potentials. The typology of ALSs used in the present study was identified for Pontieba village at the end of the cropping season 2013/2014 by Thiombiano and Le (2015).

a. Material flow analysis

Material flow analysis (MFA) is a method used to compile and visualize the stocks and flows of any material (or energy or currency) in any environment, human, or human-environment system for a given time and region (Brunner and Rechberger 2004). Usually, the following methodological steps are applied sequentially in MFA:

1. Definition of a qualitative flowchart: In this stage, the material flow analyst sets the system boundaries of the investigated system and defines the processes and flows therein. Additionally, the material flow analyst decides whether each flow has a stock or not. Figure 1 gives the qualitative flowchart of agricultural livelihood system as defined by Van den Bosch et al. (1998).

   The processes of smallholder farms are:
   - Primary production units (PPU, crops)
   - Secondary production units (SPU, livestock)
   - Redistribution units (RU, e.g., compost heap, stable)
   - Household (HH)
   - Stock
2. Data collection: The material flow analyst relies on primary flow measurements or models to populate the stocks and flows of the qualitative flowchart. Models consist mainly in but are not limited to transfer coefficients (e.g., the ratio of nutrient transferred to the crop to the total nutrient entering the process) or concentrations (e.g., concentration of nutrient in a crop). Here, all flows were informed by models or primary data collected in the framework of a nutrient monitoring (NUTMON) survey (Van den Bosch et al. 1998) conducted for 15 households, five from each ALS, from March 2013 to February 2014.
3. Application of the mass balance principle: The key feature of MFA is the application of the mass balance principle to each process found within the system boundaries. The mass balance principle can be used to calculate flows or additions to stock that cannot be measured directly or modeled otherwise. For a process without a stock, the amount of mass entering the process during the time period of interest is equal to the amount leaving this process. For a process with a stock, the amount of mass entering the process during the time period of interest is equal to the sum of amounts leaving this process and added to its stock. For instance, on Figure 1: the following equation holds for the process "Secondary production unit" (Process P4):

   $$F05 + F17 + F23 + F35 = F25 + F26 + F27 + F28 + F30 + NAS \quad (1)$$

   Where NAS is the net addition to stock. The mass balance principle also applies to elements such as nitrogen, phosphor and potassium. The present study applies the mass balance principle to derive the balances of the five aforementioned processes.

4. Interpretation: The material flow analyst interprets stocks and flows by visualizing them as a Sankey diagram and deriving various indicators. The Sankey diagram highlights the important flows and indicates the most important sources and sinks of materials, be it stocks of process within the system or imports and exports to and from the system. Indicators allow comparing the systems of different scales. For instance, in an agricultural system, the rate of recycling by composting (i.e., in the process “Redistribution unit”) could be of interest and calculated for each nutrient as follows:

$$R_{Recycling} = \frac{F31+F34}{F12+F18+F24+F30} \quad (2)$$

   Assuming that flows F32, F33, F35 are negligible.
5. Scenario work: In MFA, scenarios are alterations of stocks and/or flows through external shocks or modifications within the system, e.g., transfer coefficients. The Sankey diagram is reinterpreted and scenario values of indicators are compared to those of the status quo.

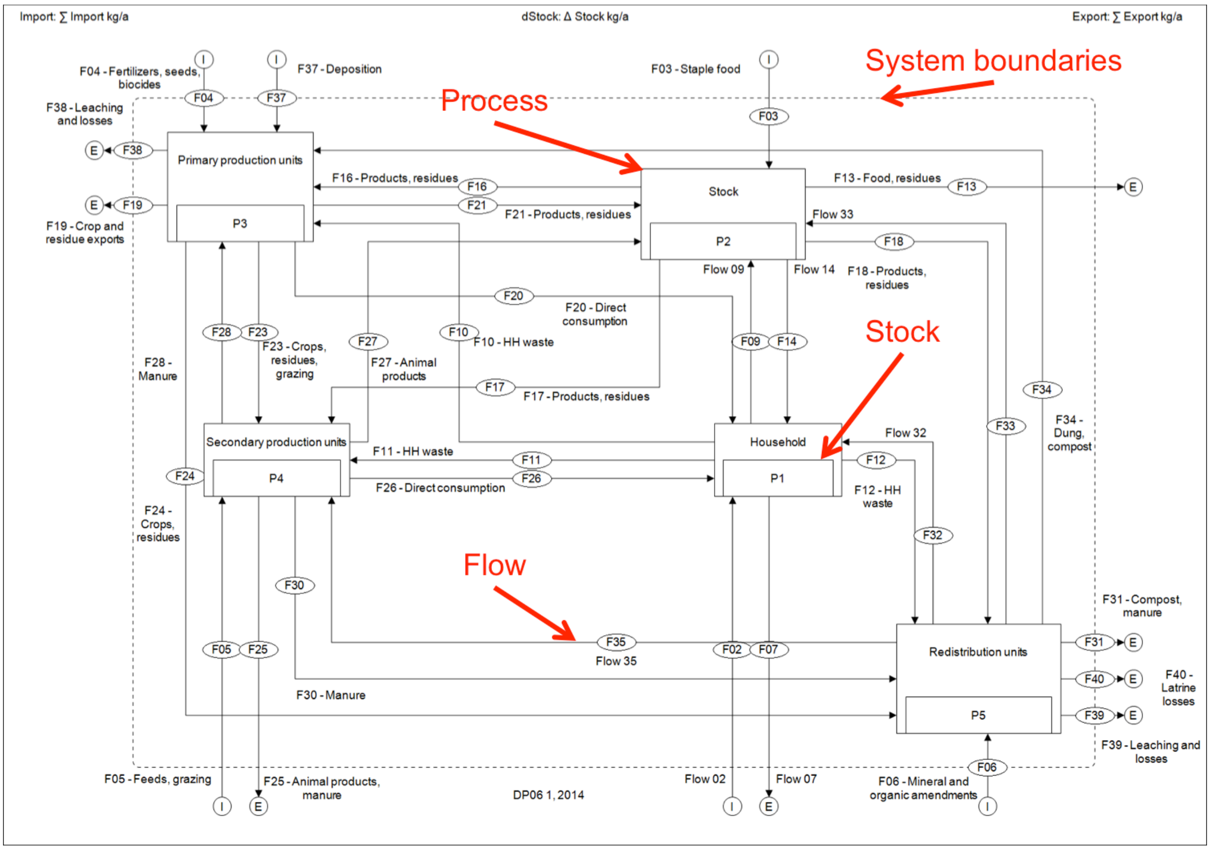


Figure 1 Example of a qualitative flowchart as starting point for conducting an MFA.

We relied on the software STAN (Cencic and Rechberger 2008) to store data and model the status quo and scenario MFAs.

b. Soft systems methodology

Soft systems methodology (SSM) is a methodology to structure complex real world problems and to develop and identify desirable and feasible changes in a heterogeneous group of actors[4]. The two first steps of SSM were applied to yield problems and improvements as seen and detailed by three groups of five smallholders representing best their ALS:

1. Expression of problem situation (1h): Collectively, group members create a comprehensive picture of the problem situation through drawing a rich picture. Individual pictures (20 minutes) were combined to one overall rich picture (40 minutes).
2. Root definition (1h30): Starting from the overall rich picture, possible improvements of the problem situation are brainstormed. The improvements are formulated as root definitions, purposeful systems conceived as relevant to exploring the problem situation. A root definition starts with "A system of activities that … ", followed by the idea, formulated as an input-output purposeful transformation of the problem situation. The root definition specifies what is transformed by whom and for what purpose. It should answer the questions abbreviated by the mnemonic CATWOE:
   "C ('customers'): Who would be victims or beneficiaries of this system were it to exist?
   A ('actors'): Who would carry out the activities of this system?
   T ('transformation process'): What input is transformed into what output by this system?
   W ('Weltanschauung'): What image of the world makes this system meaningful?
   As all farmers within an ALS group are assumed to share the same worldview, question W was not posed.
   O ('owners'): Who could abolish this system?
   E ('environmental constraints'): What external constraints does this system take as given"

c. Agricultural livelihood systems typology in Pontieba

Below is the description of the three ALS types as identified by Thiombiano and Le (2015):

- Livelihood type I: Poor, landless and subsistence-based farms:

The agricultural livelihood type I (Poor, landless and subsistence-based farms) represented 40% of the study sample. This livelihood type had the lowest asset endowment. It had in average 2.67 ha of total land holdings, meaning 0.47 ha per person. The livelihood orientation was subsistence-based as income from basic cereals (sorghum, millet and maize) formed 32.47% of annual gross income with 60.85% of cultivated land dedicated to these cereals. Only 10.74% of cultivated lands were allocated to cotton which is the main local and regional cash crop. These farms also have low labor and less transportation. They have the lowest annual gross income. Only 46,152 FCFA per person was found (USD 93.351/person). Livelihoods of these farms can be considered to be vulnerable as the annual income per person is below the national poverty line estimated to be 108,454 FCAF (USD 219.36/person/year).

- Livelihood type II: Medium-income, high-dependency, cotton-and livestock-turned

The agricultural livelihood type II (Medium-income, high-dependency, cotton-and livestock-turned) represented 40% of the study. This farm type had the highest dependency ratio (0.37). The liveli-

[4] http://www.naturwissenschaften.ch/topics/co-producing_knowledge/methods/soft_systems_methodology

hood orientation is market-turned. In effect, around 20% of the cultivated land is allocated to cotton cropping. In addition, the contribution of basic cereals income to the annual gross income (18.33%) is lower than in the case of agricultural livelihood type I. It also had a better endowment in livestock than the farm type I. The number of Tropical Livestock Unit (TLU) per capita was 0.23. The labor endowment and transportation were not significantly different for farm types I and II. The agricultural livelihood type II showed a medium annual income estimated to 101,295 FCFA/person, equivalent to USD 204.88/person/yr. This amount is nearly the poverty line in Burkina Faso, USD 219.36/person/year.

- Livelihood type III: Better-off, land-and labor-rich, cotton-and livestock-turned

The third farm type, agricultural livelihood type III (Better-off, land-and labor-rich, cotton- and livestock-turned) represented the best endowed and wealthiest farm type out of the three. It had the highest labor endowment (7 workers), the highest land holdings (4.25 ha) and the highest number of transportation (4). This last setting might play an important role in facilitating the farmer access to market, to other farmers and villages, and thereby increases his exposure to innovations and opportunities. This farm type is also market- turned like in the case of agricultural livelihood type II. The land area dedicated to cotton cropping was around 23% of cultivated. As for the livestock endowment, it was 0.35 TLU per person. The values for cotton and livestock as well as the contribution of cereal income to annual gross income (19.91%) were higher than in the case of agricultural livelihood type I, but were not significantly different from agricultural livelihood type II. The agricultural livelihood type III was the only one farm type with annual income above the poverty line in Burkina Faso. This annual income was 144,428 FCFA/person (USD 292.12/person).

SECTION IV – RESULTS AND DISCUSSION

a. Status quo material flow analyses

Figure 2 shows the MFAs of N, P, K of farm DP06 belonging to ALS type 1 (all farm MFAs available in Appendix 2).

- Nitrogen:

The largest nutrient flows in all farms of this ALS type are found in the primary production units with the maximum of 52 kg N/ha/yr. Two farms (DP06, DP07) have mineral fertilizers as largest flows, and positive soil nutrient balances of +21 and +4.1 kg N/ha/yr, respectively. The remaining three farms (DP34, DP78, and DP113) have no mineral fertilizer input and their largest flow is either crops and residues leaving the system (as marketable goods or gifts) or nutrients leached or lost otherwise to the environment. The later farms have negative soil nutrient balances, from –16 to -7.6 kg N/ha/yr. In DP06 and DP07, mineral fertilizers constitute the largest source into the system, while redistribution units are the main sinks. In DP34, DP78, and DP113, soil nutrients are the main source, while crops and residues leaving the system or nutrients leached and other losses to the environment from primary production units represent the largest sink. The highest recycling rate is 2%.

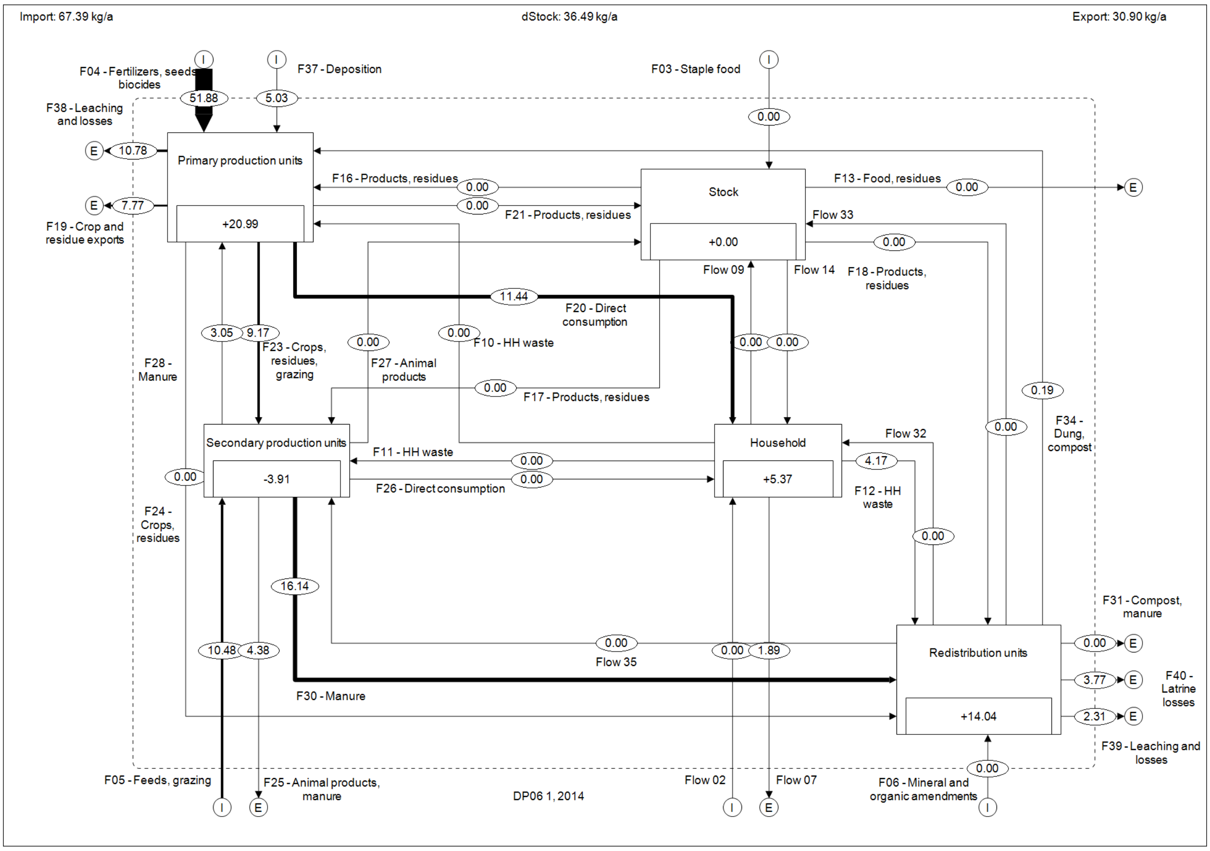
- Phosphorus:

Two farms (DP06, DP07) have mineral fertilizers as largest flows with the maximum of 43 kg P/ha/yr, and a positive soil nutrient balance. Yet almost all phosphorus from the mineral fertilizer is accumulated in the soil, resulting in soil balances of +32 to +10 kg P/a/ha, respectively. The remaining three farms (DP34, DP78, DP113) have no mineral fertilizer input and their largest flow, which are still very low, are household waste to redistribution units, manure to redistribution units, and feeds, grazing imported into secondary production units. The later farms have slightly negative soil balances, ranging -0.91 to -0-40 kg P/ha/yr. In DP06 and DP07, mineral fertilizes are the largest sources, while animal products leaving secondary production units constitute the largest sinks. In DP34, DP78, and DP113, soil nutrients, deposition, and feeds, grazing into secondary production units are the main sources, while crops and residues leaving the system, latrine losses, and animal products from secondary production units represent the largest sink. The three sources and three sinks are at similar levels. The highest recycling rate is 1%.

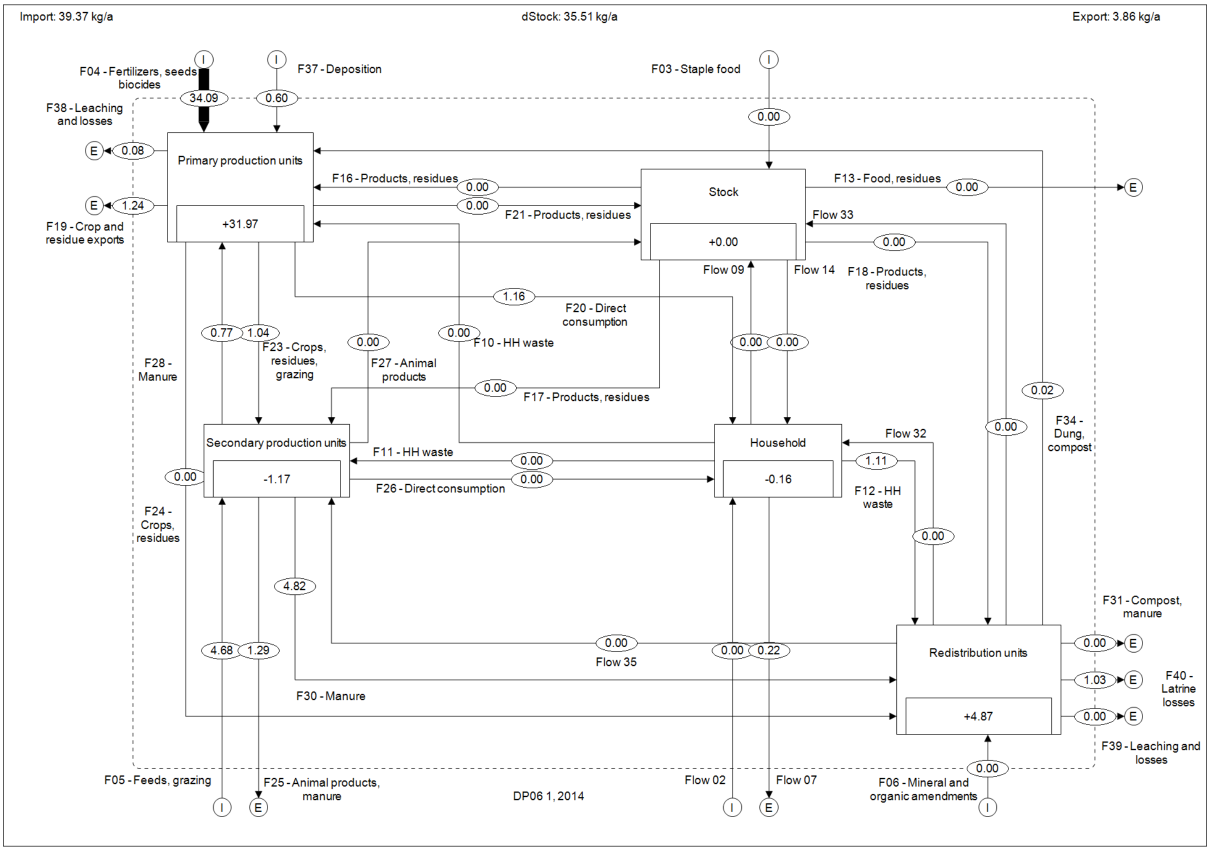
- Potassium:

There are large flows from primary production units to secondary production units through to redistribution units with a maximum of 26 kg K/ha/yr. The two farms (DP06, DP07) have large flows of crops, residues, grazing from primary to secondary production units and of manure from secondary production to redistribution units. Despite fertilizer application, soil balances of both farms are negative, with -9.1 and -6.5 kg K/ha/yr, respectively. The remaining three farms lacking mineral fertilizer input (DP34, DP78, DP113) have as largest flow either crops and residues leaving the system (as marketable goods or gifts) or crops, residues, grazing into secondary production units. The later farms have negative soil nutrient balances, from –31 to -7.7 kg K/ha/yr. In DP06 and DP07, mineral fertilizers constitute the largest source into the system, while redistribution units are the main sinks. In DP34, DP78, and DP113, soil nutrients are the main source, while crops and residues leaving the system or nutrients leached and other losses to the environment from primary production units represent the largest sink. The highest recycling rate is 2%.

N


Import: 67.39 kg/a
dStock: 36.49 kg/a
Export: 30.90 kg/a
F04 - Fertilizers, seeds, biocides
51.88
F37 - Deposition
5.03
F03 - Staple food
0.00
F38 - Leaching and losses
10.78
7.77
F19 - Crop and residue exports
Primary production units
+20.99
F16 - Products, residues
0.00
0.00
F21 - Products, residues
Stock
+0.00
F13 - Food, residues
0.00
Flow 33
0.00
Flow 09
Flow 14
F18 - Products, residues
11.44
F20 - Direct consumption
3.05
9.17
F23 - Crops, residues, grazing
0.00
0.00
F10 - HH waste
0.00
0.00
F27 - Animal products
F28 - Manure
0.00
F17 - Products, residues
0.19
0.00
F34 - Dung, compost
Secondary production units
-3.91
F11 - HH waste
0.00
0.00
F26 - Direct consumption
Household
+5.37
Flow 32
4.17
F12 - HH waste
0.00
F24 - Crops, residues
16.14
F31 - Compost, manure
0.00
Flow 35
0.00
1.89
10.48
4.38
Redistribution units
+14.04
0.00
3.77
2.31
F40 - Latrine losses
F30 - Manure
F39 - Leaching and losses
0.00
F05 - Feeds, grazing
F25 - Animal products, manure
DP06 1, 2014
Flow 02
Flow 07
F06 - Mineral and organic amendments

P


Import: 39.37 kg/a
dStock: 35.51 kg/a
Export: 3.86 kg/a
F04 - Fertilizers, seeds, biocides
34.09
F37 - Deposition
0.60
F03 - Staple food
0.00
F38 - Leaching and losses
0.08
1.24
F19 - Crop and residue exports
Primary production units
+31.97
F16 - Products, residues
0.00
0.00
F21 - Products, residues
Stock
+0.00
F13 - Food, residues
0.00
Flow 33
0.00
Flow 09
Flow 14
F18 - Products, residues
1.16
F20 - Direct consumption
0.77
1.04
F23 - Crops, residues, grazing
0.00
0.00
F10 - HH waste
0.00
0.00
F27 - Animal products
F28 - Manure
0.00
F17 - Products, residues
0.02
0.00
F34 - Dung, compost
Secondary production units
-1.17
F11 - HH waste
0.00
0.00
F26 - Direct consumption
Household
-0.16
Flow 32
1.11
F12 - HH waste
0.00
F24 - Crops, residues
4.82
F31 - Compost, manure
0.00
Flow 35
0.00
0.22
4.68
1.29
Redistribution units
+4.87
0.00
1.03
0.00
F40 - Latrine losses
F30 - Manure
F39 - Leaching and losses
0.00
F05 - Feeds, grazing
F25 - Animal products, manure
DP06 1, 2014
Flow 02
Flow 07
F06 - Mineral and organic amendments

K

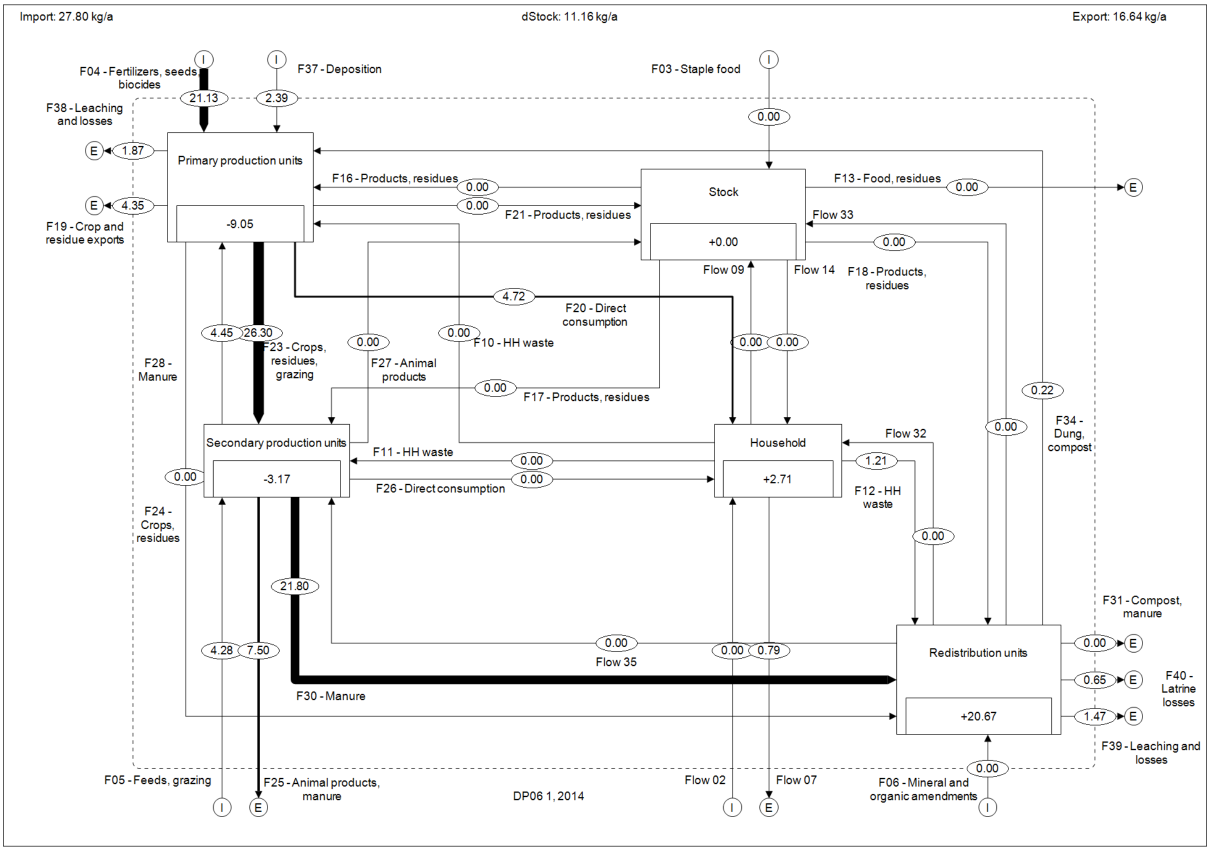


Figure 2 MFAs of N, P, K (kg/ha/yr) of ALS 1 (farm DP06).

Figure 3 shows the MFAs of N, P, K of farm DP14 belonging to ALS type 2 (all farm MFAs available in Appendix 2).

- Nitrogen:

Each of the five farms exhibits a different largest flow. The largest flow of all farms is achieved by DP17 with 48 kg N/ha/yr. It is also the only farm with a significant mineral fertilizer input (28 kg/ha/yr) and a positive soil balance. The other farms (DP14, DP23, DP32, DP33) have negative soil balances ranging from -22 to 11 kg N/ha/yr. The main sources are feeds, grazing into secondary production units in the case of DP17 and soil nutrients in all other farms. For all farms, redistribution units constitute the main sink. The highest recycling rate is 6%.

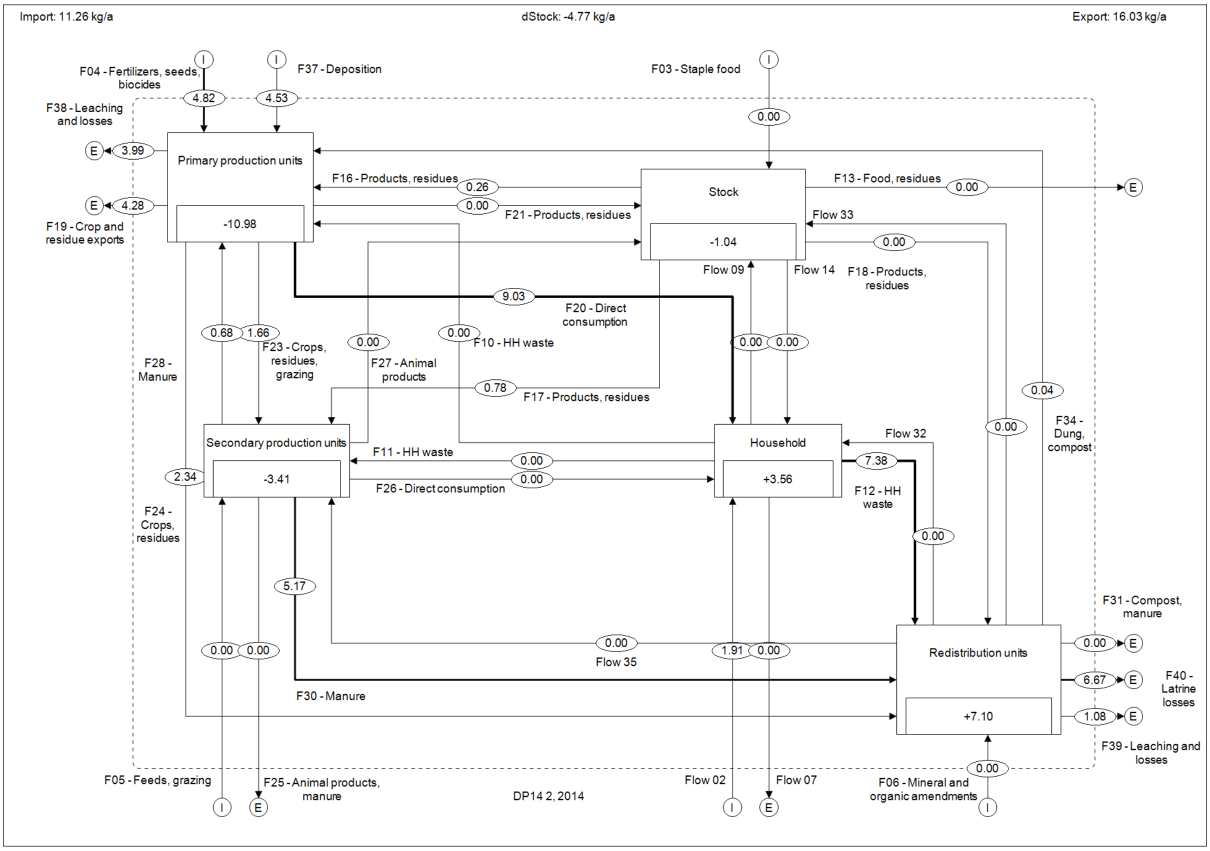
- Phosphorus:

The largest flows are either mineral fertilizers (DP14, DP17) with a maximum of 27 kg P/ha/yr and feeds, grazing into secondary production units (DP23, DP32, DP33) with a maximum of 6.8 kg N/ha/yr. The former farms have positive soil balances with amounts similar to those of mineral fertilizer inputs. The later farms have soil balances close to 0, ranging from -0.94 to 0.11 kg P/ha/yr. In the case of DP14 and DP17, the main sources are mineral fertilizers, while the soil constitutes the main sink. As for DP23, DP32, and DP33, feeds, grazing into secondary production units represent the main source, while redistribution units constitute the main sink. The highest recycling rate is 2%.

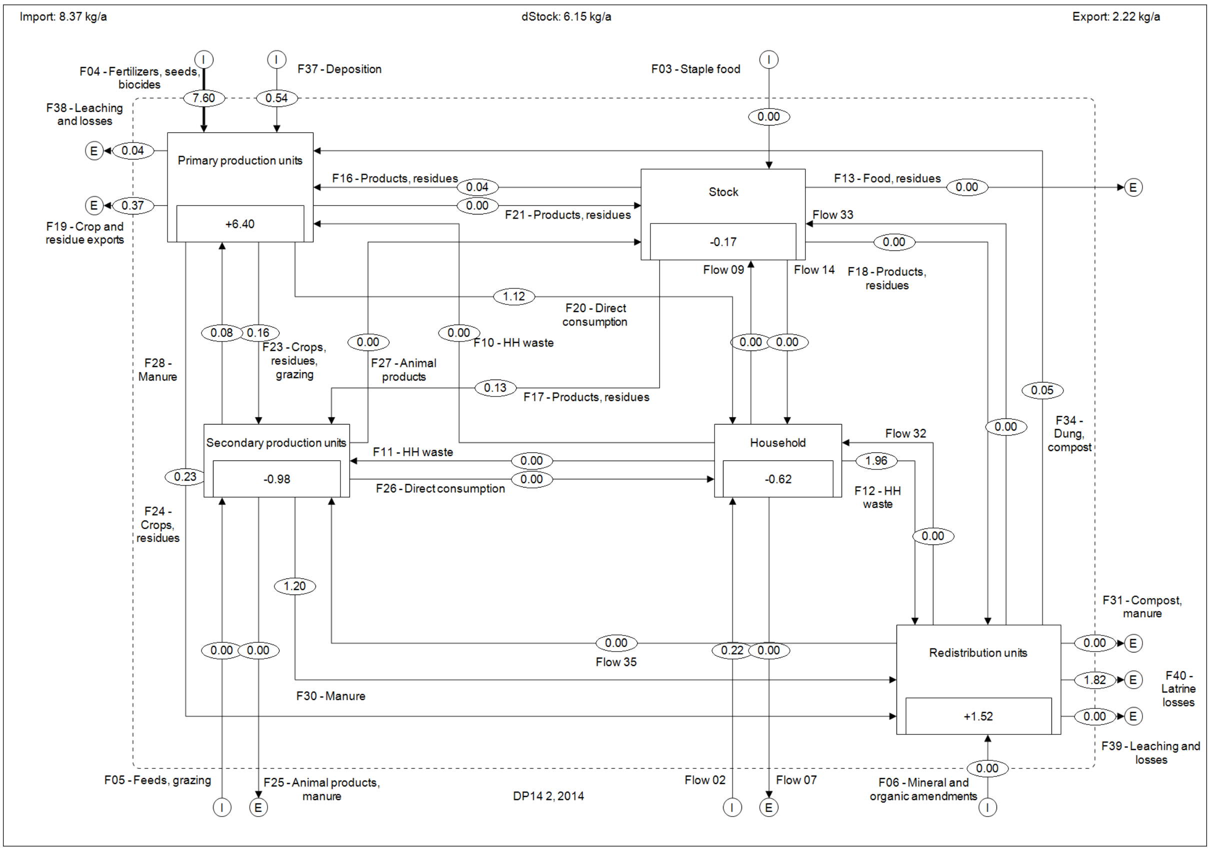
- Potassium:

Large flows link primary production units to redistribution units directly (as crops, residues) or via secondary production units (as crops, residues, grazing, then manure). However, the largest flow, 25 kg N/ha/yr, is feeds, grazing into secondary production units achieved by DP17. All farms exhibit negative soil balances, ranging from -33 to -5.1 kg K/ha/yr. In the case of DP17, the main source is feeds, grazing into secondary production units, while all other farms have the soil as main source. Redistribution units are the main sinks, except for the case of DP23, in which potassium leaves the system mainly through crops and residues leaving the system (as marketable goods or gifts). The highest recycling rate is 16%, achieved by DP17.

N


Import: 11.26 kg/a
dStock: -4.77 kg/a
Export: 16.03 kg/a
F04 - Fertilizers, seeds, biocides
4.82
F37 - Deposition
4.53
F03 - Staple food
0.00
F38 - Leaching and losses
3.99
Primary production units
-10.98
F16 - Products, residues
0.26
F21 - Products, residues
0.00
4.28
F19 - Crop and residue exports
Stock
-1.04
F13 - Food, residues
0.00
Flow 33
0.00
Flow 09
Flow 14
F18 - Products, residues
9.03
F20 - Direct consumption
0.68
1.66
F23 - Crops, residues, grazing
0.00
0.00
F10 - HH waste
0.00
0.00
F27 - Animal products
F28 - Manure
0.78
F17 - Products, residues
0.04
0.00
F34 - Dung, compost
Secondary production units
-3.41
Household
+3.56
Flow 32
F11 - HH waste
0.00
7.38
2.34
0.00
F26 - Direct consumption
F12 - HH waste
F24 - Crops, residues
0.00
5.17
F31 - Compost, manure
0.00
1.91
0.00
Redistribution units
+7.10
0.00
0.00
Flow 35
6.67
F40 - Latrine losses
F30 - Manure
1.08
F39 - Leaching and losses
0.00
F05 - Feeds, grazing
F25 - Animal products, manure
DP14 2, 2014
Flow 02
Flow 07
F06 - Mineral and organic amendments

P


Import: 8.37 kg/a
dStock: 6.15 kg/a
Export: 2.22 kg/a
F04 - Fertilizers, seeds, biocides
7.60
F37 - Deposition
0.54
F03 - Staple food
0.00
F38 - Leaching and losses
0.04
Primary production units
+6.40
F16 - Products, residues
0.04
F21 - Products, residues
0.00
0.37
F19 - Crop and residue exports
Stock
-0.17
F13 - Food, residues
0.00
Flow 33
0.00
Flow 09
Flow 14
F18 - Products, residues
1.12
F20 - Direct consumption
0.08
0.16
F23 - Crops, residues, grazing
0.00
0.00
F10 - HH waste
0.00
0.00
F27 - Animal products
F28 - Manure
0.13
F17 - Products, residues
0.05
0.00
F34 - Dung, compost
Secondary production units
-0.98
Household
-0.62
Flow 32
F11 - HH waste
0.00
1.96
0.23
0.00
F26 - Direct consumption
F12 - HH waste
F24 - Crops, residues
0.00
1.20
F31 - Compost, manure
0.00
0.22
0.00
Redistribution units
+1.52
0.00
0.00
Flow 35
1.82
F40 - Latrine losses
F30 - Manure
0.00
F39 - Leaching and losses
0.00
F05 - Feeds, grazing
F25 - Animal products, manure
DP14 2, 2014
Flow 02
Flow 07
F06 - Mineral and organic amendments

K

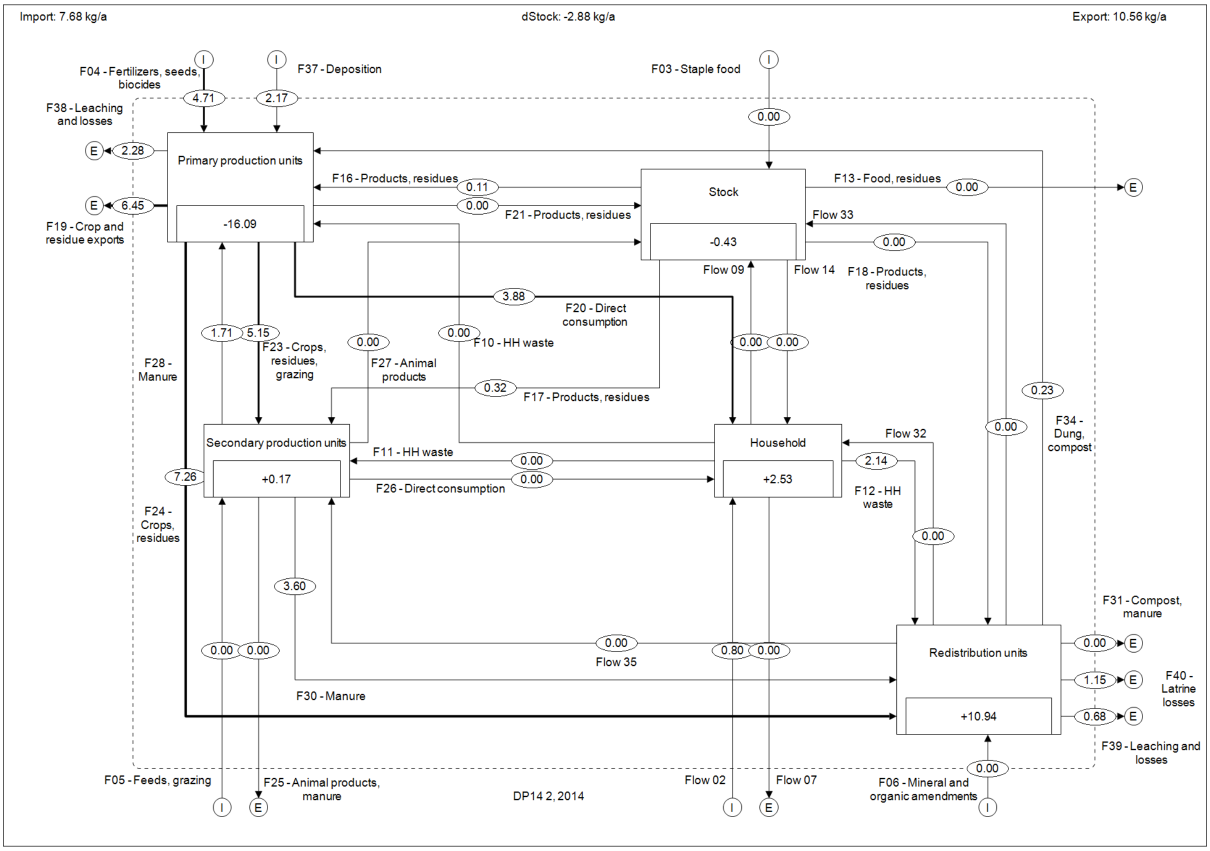


Figure 3 MFAs of N, P, K (kg/ha/yr) of ALS 2 (farm DP14).

Figure 4 shows the MFAs of N, P, K of farm DP30 belonging to ALS type 3 (all farm MFAs available in Appendix 2).

- Nitrogen:

The largest nutrient flows in all farms of this ALS type are feeds, grazing into the secondary production units with a maximum of 145 kg N/ha/yr. While all farms have mineral fertilizer inputs, such inputs remain small relatively to the flows into and out of secondary production units. All farms have negative soil balances, ranging from -24 to -0.85 kg N/ha/yr. Feeds, grazing into secondary production units are the main source into ALS 3 farms except in the case of farm DP45, in which soil nutrients slightly surpass feeds, grazing into secondary production units (24 and 21 kg N/ha/yr). In all farms, redistribution units and animal products constitute the main sinks at similar levels. The highest recycling rate is 24% achieved by farm DP30.

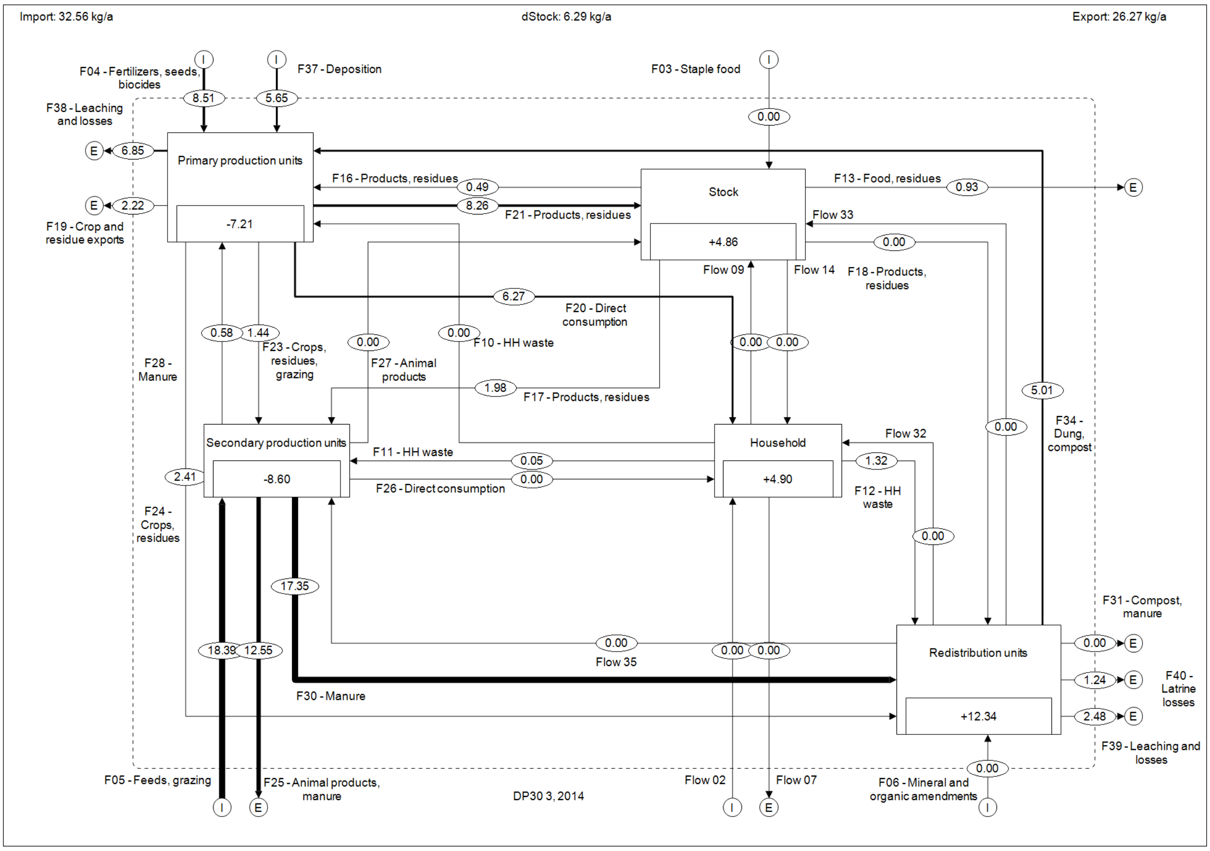
- Phosphorus:

The largest nutrient flows in all farms of this ALS type are feeds, grazing into the secondary production units with a maximum of 75 kg P/ha/yr. All farms have positive soil balances, at amounts just below those of fertilizer inputs. Feeds, grazing into the secondary production units constitute the main source of phosphorus into the farms. There are three sinks at similar levels: animal products from secondary production, soils, and redistribution levels. The highest recycling rate is 5% achieved by farm DP30.

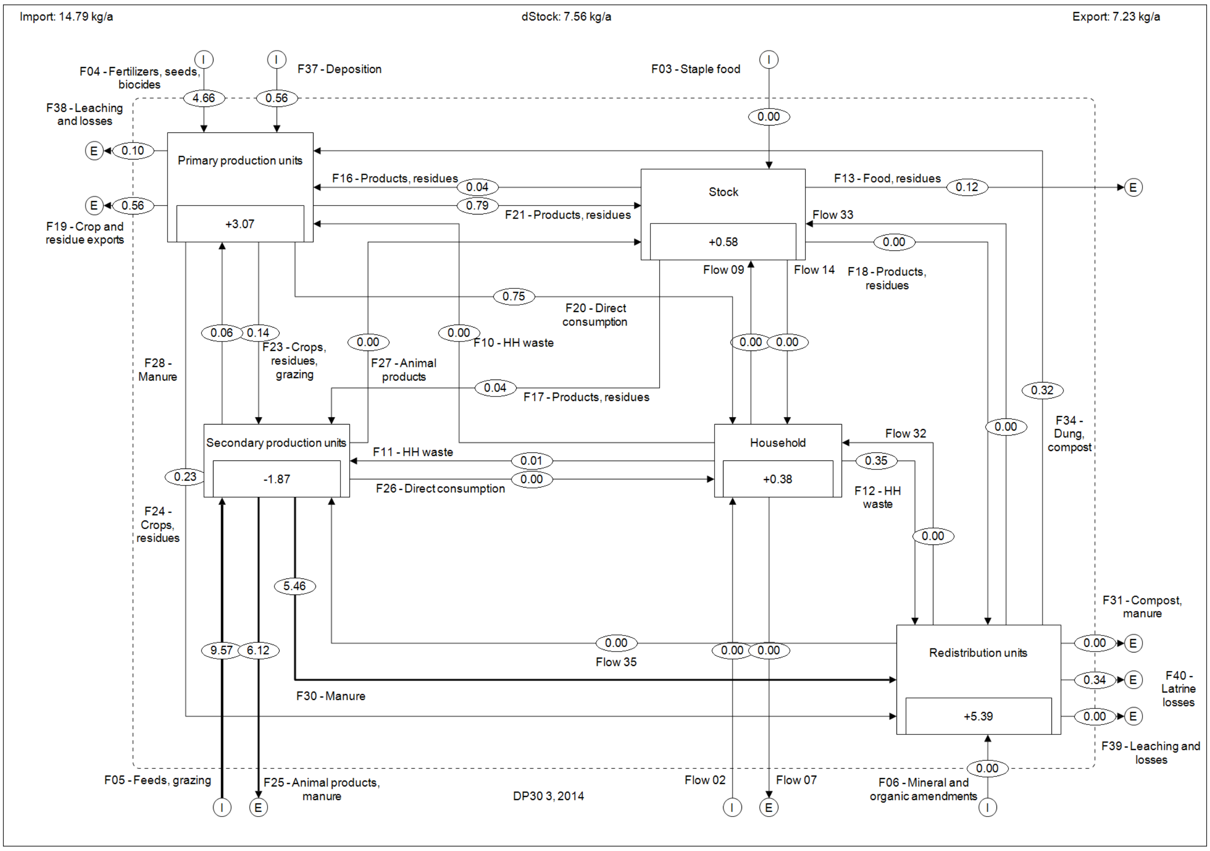
- Potassium:

The largest flows are found at the secondary production units with a maximum of 75 kg K/ha/yr. In the case of farms DP41 and DP112, feeds, grazing into secondary production units constitute the largest flows, while in the other farms, manure from and crops, residues, crazing into secondary production units occupy this position. In all cases, soil nutrient balances are largely negative, ranging from -34 to 11 kg K/ha/yr, to the benefit of livestock production. Main sources alternate between soil nutrients and feeds, grazing into secondary production units. Redistribution units represent by far the main sinks, followed by animal products from secondary production units. The highest recycling is 8% achieved by farm DP30.

N


Import: 32.56 kg/a
dStock: 6.29 kg/a
Export: 26.27 kg/a
F04 - Fertilizers, seeds, biocides
8.51
F37 - Deposition
5.65
F03 - Staple food
0.00
F38 - Leaching and losses
6.85
Primary production units
-7.21
F16 - Products, residues
0.49
8.26
F21 - Products, residues
Stock
+4.86
F13 - Food, residues
0.93
Flow 33
0.00
2.22
F19 - Crop and residue exports
Flow 09
Flow 14
F18 - Products, residues
6.27
F20 - Direct consumption
0.58
1.44
F23 - Crops, residues, grazing
0.00
F27 - Animal products
0.00
F10 - HH waste
0.00
0.00
F28 - Manure
1.98
F17 - Products, residues
5.01
0.00
F34 - Dung, compost
Secondary production units
-8.60
F11 - HH waste
0.05
0.00
F26 - Direct consumption
Household
+4.90
Flow 32
1.32
F12 - HH waste
2.41
F24 - Crops, residues
0.00
17.35
F31 - Compost, manure
18.39
12.55
0.00
Flow 35
0.00
0.00
Redistribution units
+12.34
0.00
1.24
F40 - Latrine losses
2.48
F30 - Manure
F39 - Leaching and losses
0.00
F05 - Feeds, grazing
F25 - Animal products, manure
DP30 3, 2014
Flow 02
Flow 07
F06 - Mineral and organic amendments

P


Import: 14.79 kg/a
dStock: 7.56 kg/a
Export: 7.23 kg/a
F04 - Fertilizers, seeds, biocides
4.66
F37 - Deposition
0.56
F03 - Staple food
0.00
F38 - Leaching and losses
0.10
Primary production units
+3.07
F16 - Products, residues
0.04
0.79
F21 - Products, residues
Stock
+0.58
F13 - Food, residues
0.12
Flow 33
0.00
0.56
F19 - Crop and residue exports
Flow 09
Flow 14
F18 - Products, residues
0.75
F20 - Direct consumption
0.06
0.14
F23 - Crops, residues, grazing
0.00
F27 - Animal products
0.00
F10 - HH waste
0.00
0.00
F28 - Manure
0.04
F17 - Products, residues
0.32
0.00
F34 - Dung, compost
Secondary production units
-1.87
F11 - HH waste
0.01
0.00
F26 - Direct consumption
Household
+0.38
Flow 32
0.35
F12 - HH waste
0.23
F24 - Crops, residues
0.00
5.46
F31 - Compost, manure
9.57
6.12
0.00
Flow 35
0.00
0.00
Redistribution units
+5.39
0.00
0.34
F40 - Latrine losses
0.00
F30 - Manure
F39 - Leaching and losses
0.00
F05 - Feeds, grazing
F25 - Animal products, manure
DP30 3, 2014
Flow 02
Flow 07
F06 - Mineral and organic amendments

K

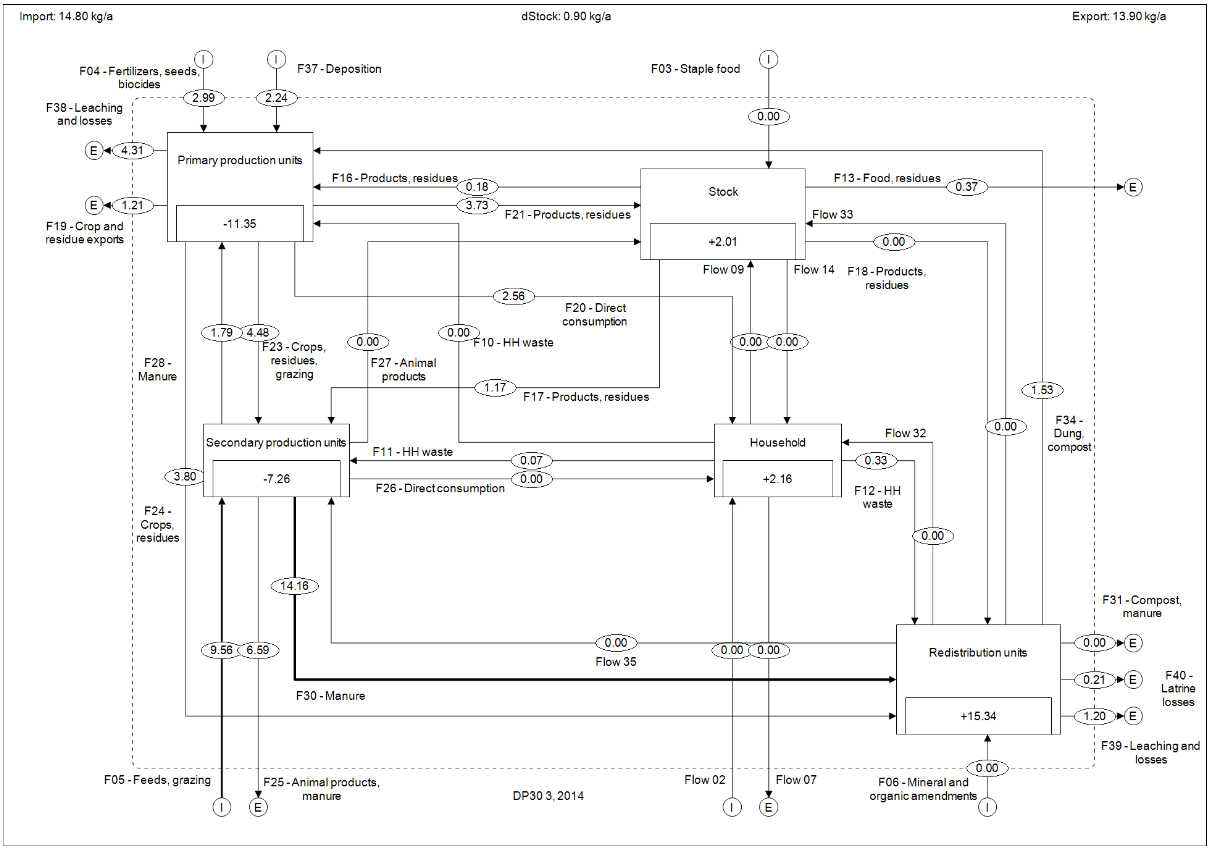


Figure 4 MFAs of N, P, K (kg/ha/yr) of ALS 3 (farm DP30).

To summarize results of status quo MFAs, one can observe both differences and similarities between the three ALS types. There are different processes dominating the farms, with ALS 1 and 3 showing a clear picture. The ALSs present different scales of flows, with maximum flows ranging from 48 to 145 kg N/ha/yr, for instance. Similarities include low recycling rates and, as a consequence, redistribution units as an important sink. Also, phosphorus from mineral fertilizers accumulates almost entirely in soils.

b. Scenarios of recycling

The key result of the status quo MFAs is that redistribution units are the main sinks, regardless of which ALS type is considered. In line with the research questions, two questions guide the development of scenarios, namely

- What could be the contribution of redistribution units to supply of nutrients to primary production units?
- What is the mineral fertilizer need considering contribution of redistribution units?

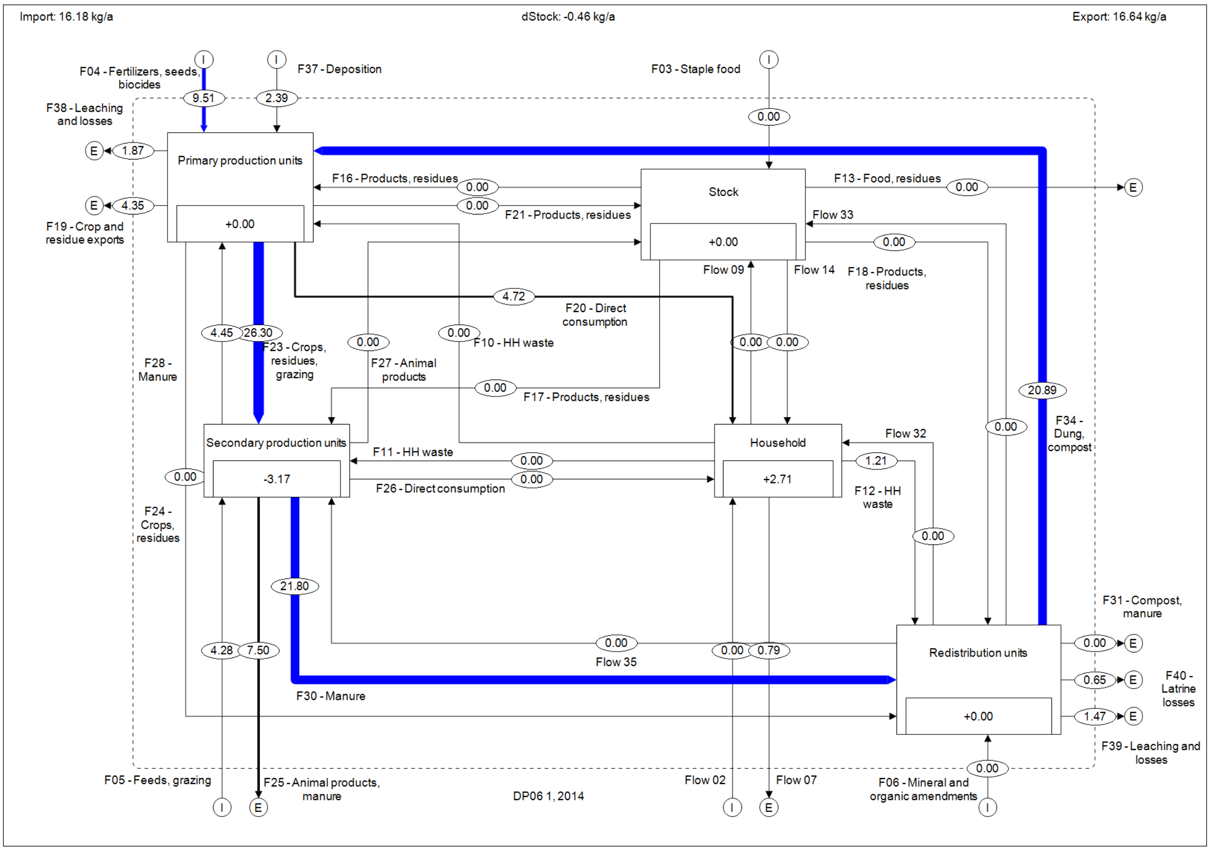
To answer the first question, we investigate the potential of redistribution units to fill negative nutrient balances of primary production units or, even better, replace mineral fertilizers. We present the scenario MFAs of three farms belonging each to a different ALS type (cf. Figure 5). Concretely, the balance in redistribution units is set to zero, while all other flows into and out of redistribution units are kept to amounts of the status quo except for flow F 34 (dung, compost), whose value is then calculated through the application of the mass balance principle. In other words, in the scenario, flow F 34 takes the same value as the balance of the redistribution unit. If F 34 is smaller than the absolute value of the balance of the primary production unit (i), the balance is recalculated, again with the mass balance principle, to reflect the reduced nutrient mining. If F

34 is larger than the absolute value of the balance of the primary production unit (ii), the balance of the primary production unit is set to zero and F 04 (mineral fertilizer) is recalculated using the mass balance principle. In the latter case, the new F04 is the mineral fertilizer need after recycling.

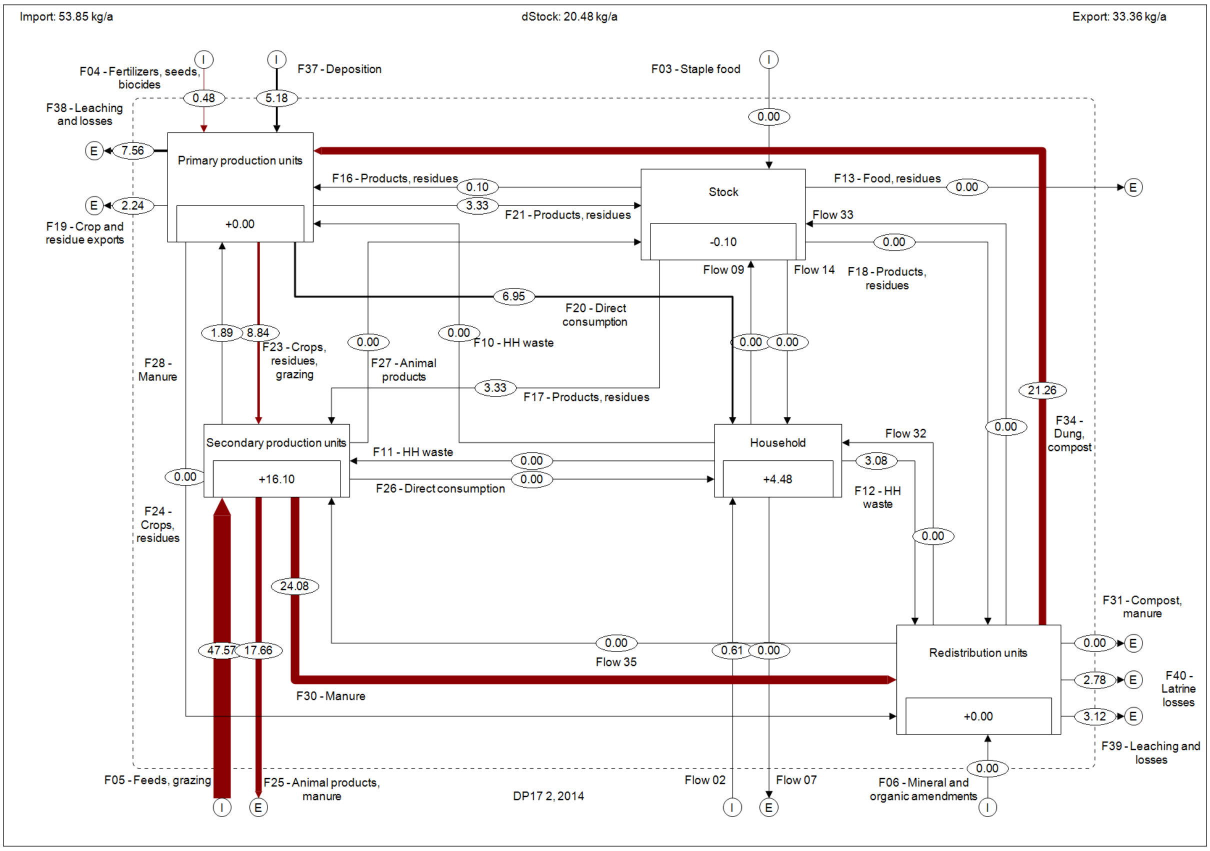
To answer the second question, we calculate ALS averages and report maxima and minima of mineral fertilizer needs after recycling defined above (ii) and compare results from an ALS and nutrient points of view.

In farm DP06 (ALS 1, see Figure 5), not only redistribution units can fill the negative balance of 9.1 kg K/ha/yr, but it can also reduce the need for mineral fertilizers by 50%. Dung and compost become one of the largest flows in the system, twice as a large as the mineral fertilizer flow. The main source remains mineral fertilizers, while the main sink becomes animal products being exported. In farm DP17 (ALS 2), in which the nitrogen soil balance is positive at 7.8 kg N/ha/yr, redistribution units reduce the need for mineral fertilizers by nearly 100%. The main source remains feeds, grazing, while the main sink becomes animal products. In farm DP45 (ALS 3), again for nitrogen, redistribution units can only halve the negative balance, reducing it from 24 to 10 kg N/ha/yr. In other words, redistributing compost and dung allows doubling the lifetime of the nitrogen soil mine.

K, DP06, ALS 1



N, DP17, ALS 2



N, DP45, ALS 3

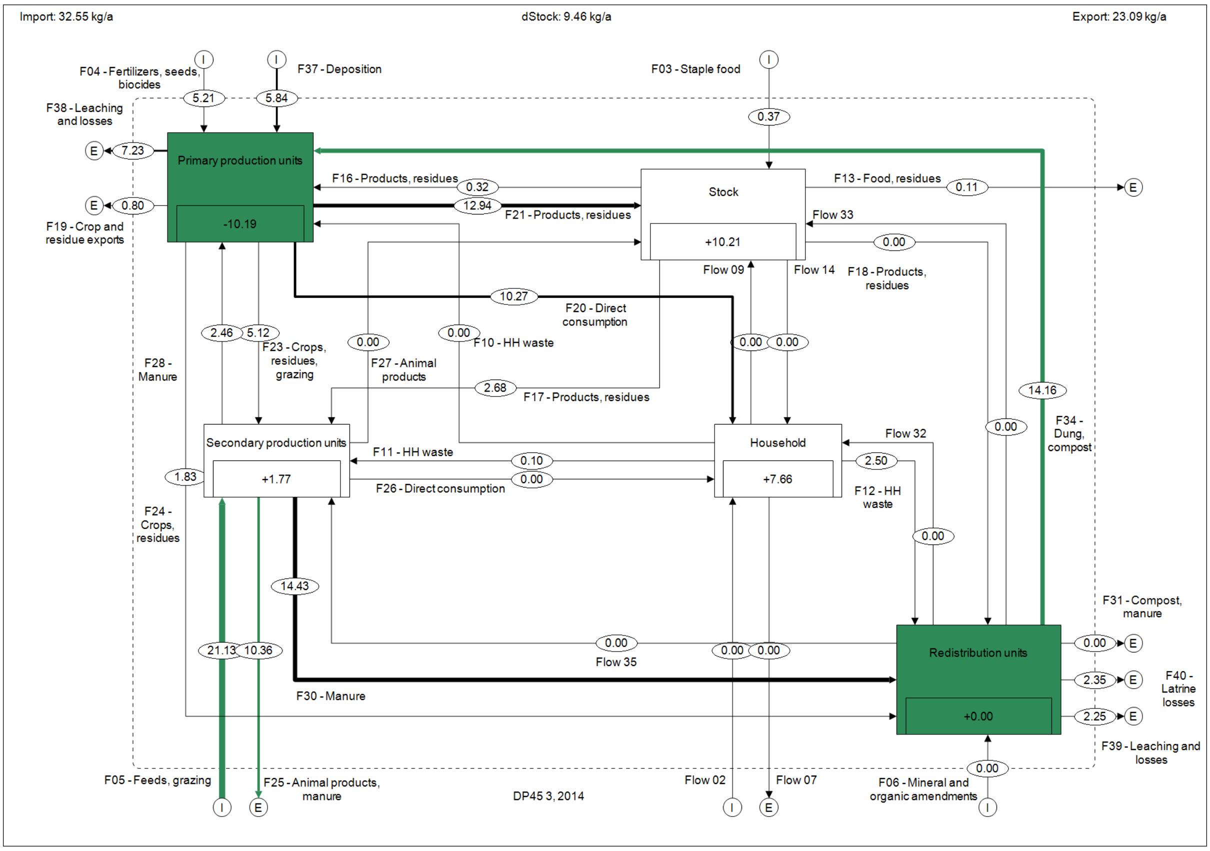


Figure 5 Scenario MFAs of three exemplary farms belonging each to a different ALS type. Large flows or important processes are highlighted in colour.

Figure 6 shows the averages, minima, and maxima of mineral fertilizer needs after recycling. Negative needs mean that the amounts from recycling surpass the needs for crop production at levels of the status quo. In average, negative needs occur for nitrogen in the case of ALS 3, for phosphorus in all ALSs, but never in the case of potassium. Also, the highest average needs are observed for potassium. The range between maxima and minima are striking for the cases of nitrogen and phosphorus in the case of ALS 3. The negative needs highlight the potential for nutrient exchange at the level of compost and dung level. Nutrient exchange already takes place at the level of fodder.

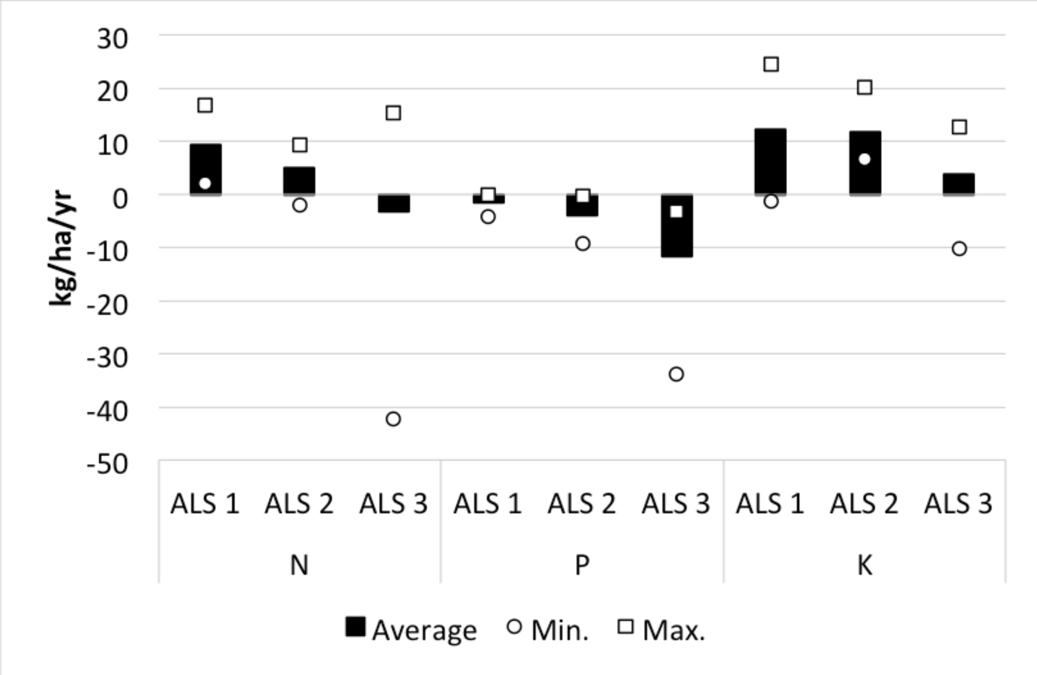


Figure 6 New fertilizer needs after fully tapping recycling potential. Negative values represent the opportunity to export nutrients to other farms.

c. Smallholder improvements

Table 1 exhibits which improvements/transformations processes were brainstormed and detailed by the different ALSs (see Appendix 3 for further details on the improvements/transformation processes).

- Some shared improvements, but not same purposes or other aspects, e.g., environmental constraints or involved actors (sow early).
- Many suggested improvements go beyond nutrient management (e.g., pest management, access to credit).
- Improvements regarding animal productivity are not mentioned by ALS group 1, as expected. ALS group 1 possesses no or little livestock.
- No improvement shared by all three ALSs (acceptance of a single policy?).

ALS 1 and ALS 3 named a transformation process linked to recycling: transporting compost and manure to remote plots. The constraints evoked to execute such a transformation are the following:

- Availability of financial resources,
- Roads,
- Labor (if road is to be constructed),
- And awareness of state mechanisms or private projects for training in composting and acquisition of transport equipment.

Table 1 Improvements/transformation processes brainstormed and detailed by the three ALSs.

Transformation process	Purpose	ALS 1	ALS 2	ALS 3
Construct a low stone wall	Fight erosion and keep nutrients	X		X
Transport compost and manure to remote plot	Enrich soil	X		X
Enrich soil	Enrich soil, fight striga (witch weed)	X	X	
Weed after rain	Fight striga (witch weed)	X		
Sow early	Fight striga (witch weed)	X		
Better maintain little dykes	Keep spread fertilizers on plot, facilitate access	X		
Create a grouping warranty fund	Facilitate access to credit for farmers	X		X
Get better access to improved seeds	Increase production yield		X	
Get better access to phytosanitary treatment	Fight insects		X	
Produce strict pluvial rice instead of sorgo	Fight flooding		X	
Make livestock farming more profitable	Improve animal care, reinvest in farm		X	X
Surround/protect market garden	Protect against animals		X	
Reforest	Better distribute rain			X
Sow earlier	Fight effects of water stagnancy			X
Rotate cotton and sorgo	Fight striga (witch weed), increase soil fertility			X

d. Interpretation of material flows

Recycling represents an interesting material potential to reduce fertilizer inputs, i.e., for sustainable intensification, or at least to reduce negative soil balance in smallholder farms of Pontieba. Yet replacing mineral by organic fertilizers is certainly not without effects on crop yields. The combined application of mineral and organic fertilizers can potentially lead to lower or higher yields than sole application (Chivenge et al. 2011; Pincus et al. 2016), so that such a combined application should be tested in the local conditions. Based on this empirical evidence, implementing transfers of dung and compost among farms (inter-farm transfers/exchanges) can then achieve optimal combinations of mineral and organic fertilizers. In other words, while inter-farm nutrient exchange already exists at the level of fodder, such exchange should also exist at the compost and dung level.

In this study, we presented the potentials of recycling by assuming nutrient losses in compost heaps and stables as defined in NUTMON models (Van den Bosch et al. 1998). However, such losses are very much linked to farmer practices, e.g., with respect to manure storage (Tittonell et

al. 2010). Prolonged manure storage periods can lead to the loss of ca. 70% of N, P, and K contained in manure.
The composting process requires amendments for activation. Local sources include human excreta and amendments available on local markets. In Pontieba, people do their business in the bush. The absence of latrine makes collection difficult. Moreover, social barriers must probably be overcome to diffuse the practice of collecting and using human excreta for the purpose of crop production (Andersson 2015). Here, anthropologists would certainly help understand these barriers. In contrast, amendments are readily available on local markets but are costly. In this case, a partial shift from subsidizing only mineral fertilizer, as it is the case in most of Africa (Druilhe and Barreiro-Hurlé 2012), to subsidizing amendments could be an interesting strategy to support composting.
Barriers to composting mentioned by farmers include mainly the availability of labor and training. Also, farmers believe that the state or a private project should take the leading role in training them to produce compost. The need for knowledge mentioned in Pontieba is in agreement with research conducted elsewhere in Sub-Saharan Africa (Mustafa-Msukwa et al. 2011).

e. Outlook on indicators of sustainability assessment based on material flow analysis

MFA-based indicators can be combined with other types of indicators to answer (research) questions going beyond material considerations. Sustainability assessments typically include economic and social indicators that are not necessarily material (Elkington 1998, 1994). As, ultimately, we would like to contribute to the sustainable intensification of smallholder farming systems, the MFA results and derived indicators for the Pontieba ALSs should be used in conjunction with other indicators to allow for sustainability assessments informing sustainable intensification. In the following paragraphs, we suggest and describe an approach to do so.

In research on the sustainability of ALSs, one can distinguish two types of indicators: problem- and solution-based indicators. Soil nutrient balances and return to labour are typical problem-based indicators. Such indicators are easily quantifiable and tailored for monitoring and evaluation as performed with the NUTMON framework (Van den Bosch et al. 1998). While they indicate what or where is the problem and the extent of the problem, they do not indicate what should be done in order to alleviate a specific problem. In contrast, solution-based indicators for ALSs are developed in the framework of socio-ecological resilience (Folke et al. 2002). Solution-based indicators provide entry points to increase the resilience of ALSs against stress and shocks such as climate change. Typical indicators are social network structure contributing to self-organisation and financial capacity as well as functional and response diversity contributing to buffer capacity (Ifejika Speranza et al. 2014). Both self-organization and buffer capacity in addition to learning capacity are capacities enhancing resilience of a system to stress and shocks. The difficulty here lies in the operationalization of such capacities into indicators, as the former describe qualities of a system. Moreover, the solution-based literature remains vague with respect to the nature of the stress and shock, often referring to climate change alone. A focus on specific shocks understood as problems, in other words indicators linking problems and solutions, could help design more effective action.

The methodology of metal criticality determination or Yale criticality methodology is a methodology linking problems to solutions in the field of metal usage in industry (Graedel et al. 2012). The methodology allows assessing how critical a metal (as element) is to a corporation, a country, and the globe as a whole. Its developers claim that it is a useful tool for studies of resource sustainability. Three dimensions make up criticality: supply risk, vulnerability to supply restriction, and environmental implications. The dimensions are further disaggregated into components, which are in turn broken down into indicators using a scale from 0% (low criticality) to 100% (high criticality). Equal weights are given to indicators within a component and equal weights are given to components within a criticality dimension. Criticality is a fairly popular concept both in science and practice. One prominent example is General Electric increasing rhenium recycling from jet turbines following a corporate criticality assessment (Graedel and Reck 2016). The European Union has developed its own criticality determination methodology, which goes beyond metals to include e.g., coking coal and pulpwood (European Commission 2014). The EU critical raw materials methodology distinguishes only two criticality dimensions: supply risk and economic importance, similar to supply risk and vulnerability to supply restriction of the Yale criticality methodology, respectively. For further information on the rationale of components and indicators and how the latter are calculated, the reader is referred to Graedel et al. (2012). Supply risk is also evaluated on the long-term for the global scale. Environmental implications are informed by the cradle-to-gate environmental impacts of metal production. The Yale criticality methodology has been adapted to assess water and gravel criticalities (Ioannidou et al. in review; Sonderegger et al. 2015).

The Yale criticality methodology provides an interesting starting point for developing indicators of nutrient sustainability assessments for systems ranging from smallholder farms to villages to an entire region. Adaptations are needed to reflect the following aspects:

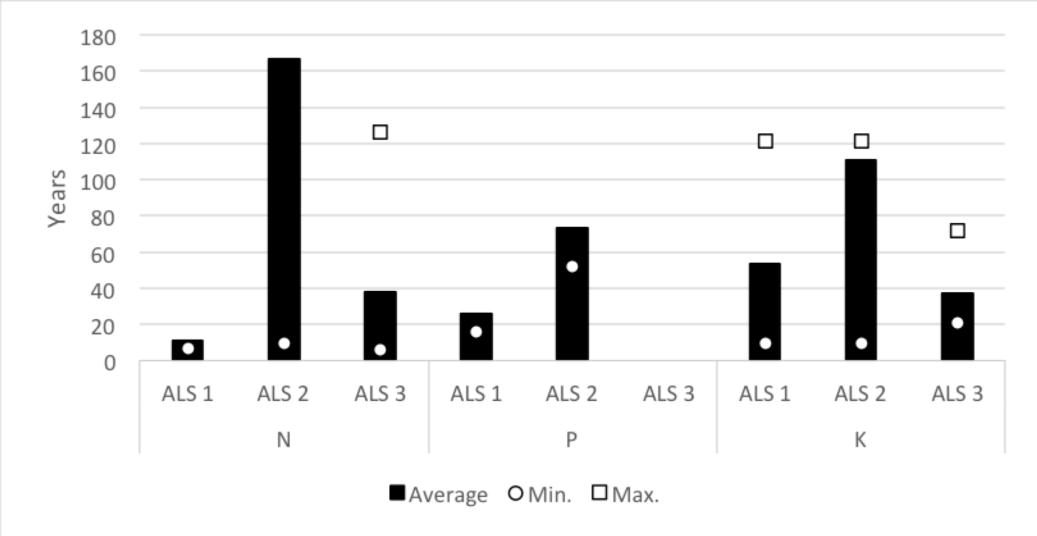
- Closely embedded within ecosystems, smallholder farms are not corporations.
- Soil nutrients are not substitutable.
- Nutrients fulfil other functions than crop growth support such as supporting biological processes which in turn maintain soil fertility.
- Unlike countries and corporations supplied with metals from mines spread all over the world, the soil is the main source of nutrients in smallholder farms. This mine can be recharged by applying mineral and organic fertilizers.

Table 2 presents the components and respective candidate indicators for criticality determination applied to smallholder farms. In the adapted methodology, vulnerability to supply restriction becomes resilience to supply restriction. The literature on resilience indicators presented above as solution-based indicators provides the components and pool of related indicators to evaluate the resilience to supply restriction. In supply risk, the depletion time of the soil stock is calculated by dividing the soil nutrient stock by the nutrient balance informed by MFA. In resilience to supply restriction, the ratio of organic fertilizers to the sum of organic fertilizers, soil nutrients mined, and mineral fertilizers yields the reliance on own resources. Again, this indicator is informed by MFA. As for social network structure, various network metrics can be here of interest. But perhaps more importantly, indicators based on social networks demonstrate the need for indicator sets linking solutions to problems. Social networks exist only for a specific process, e.g., collaboration in a policy process (Carrington et al. 2005; Ingold 2011).

Table 2 Suggested components and candidate indicators of a methodology for nutrient criticality determination at smallholder farm level.

Supply risk		Resilience to supply restriction		Environmental implications	
Components	Indicators	Components	Indicators	Components	Indicators
Pedological	- Depletion time of soil stock	Buffer capacity	- Human capacity for internal innovation - Labor	Environmental impacts of mineral fertilizer consumption	- Greenhouse gas emissions - Cumulative energy demand - Cumulative water demand - Total environmental impacts
Technological	- Plowing techniques	Self organization	- Social network structure - Reliance on own resources	Environmental impacts of fertilizer application	- Eutrophication - Soil salinization
Nutrient-uptake	- Uptake mechanisms at soil-crop interface	Capacity for training	- Access to training		
Agrobiogenetical	- Plant conversion efficiency				

After suggesting components and candidate indicators of a new nutrient criticality methodology, indicators must be operationalized and indicator values be transformed onto a scale from 0% to 100% to allow for aggregation to single scores of supply risk, resilience to supply restriction, and environmental implications. Figure 7 presents two examples of operationalization: depletion time of soil stock (above) and reliance on own resources (below). As in Figure 6, averages, maxima, and minima for the ALSs of Pontieba are computed. In the case of depletion time (above), some values do not exist due to positive soil nutrient balances, i.e., accumulation of nutrients in soils, mainly in the case of phosphorus. In the case of nitrogen, the differences between the three ALS groups are striking, as the average depletion time ranges from some 10 to 170 years. ALS 1 and ALS 3 have short nitrogen and potassium depletion times compared to ALS 2. In the case of reliance on own resources (above), no average surpasses 50%. In the case of nitrogen and potassium, no maximum surpasses 50%. Contrary to depletion time, the operationalization of reliance on own resources offers a straightforward transformation to a 0-100% scale. For instance, a reliance on own resources of 25% as in ALS 1 for nitrogen corresponds to 75% on the criticality scale.



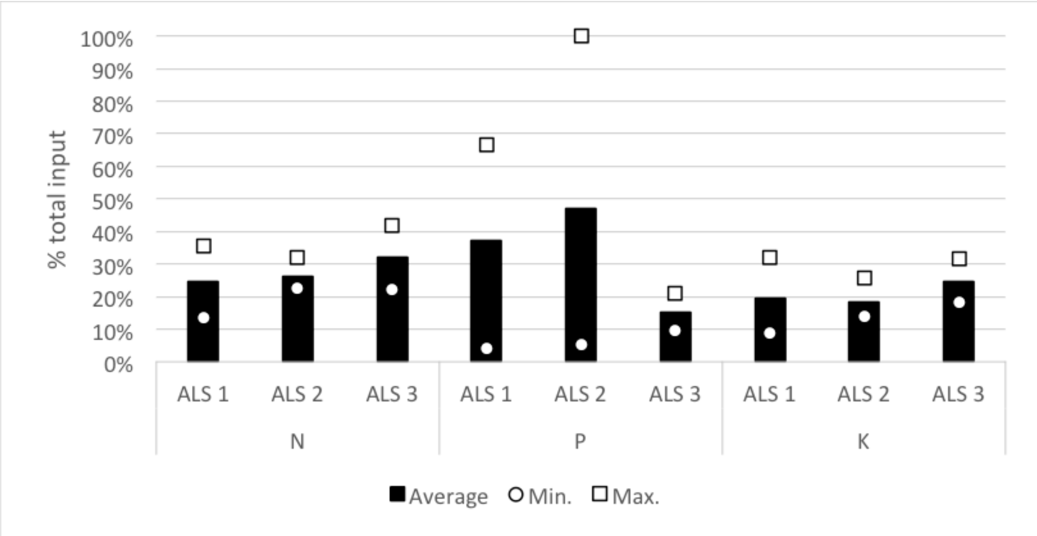


Figure 7 Values of soil stock depletion time (above) and reliance (below) on own nutrients for N, P, K in ALSs of Pontieba.

SECTION V – CONCLUSIONS AND RECOMMENDATION

a. Conclusions

The present study demonstrates how one can perform a material flow analysis on smallholder farming systems to inform policies of sustainable intensification from a systems analysis perspective. The NUTMON framework offers a reliable and sufficient data collection procedure for such an endeavour. The STAN software allows processing NUTMON data into a material flow analysis. The main findings of the study are the following:

- The three ALSs in Pontieba exhibit different processes dominating the system in terms of flow sizes.
- The three ALSs in Pontieba exhibit different scales in terms of flow sizes.
- Redistribution units are the largest sinks of nitrogen, phosphorus, and potassium in all three ALSs.
- Recycling compost and manure from redistribution to primary production units could substantially reduce negative soil nutrient balances and, at best, totally replace mineral fertilizers.
- Smallholding farmers seem to lack the necessary knowledge to operate composting facilities.
- MFA-based indicators such as recycling rates can be combined with further indicators to assess the criticality of nutrients to smallholder farming systems.

b. Recommendations

- Recycling is a promising option in all three ALSs, yet potentials identified in this study should be further scrutinized with respect to the effects on crop yield and nutient losses in the composting process.
- Further MFA research should include broader temporal system boundaries, i.e., beyond one year to capture the effects of cycles longer than one year, e.g., crop rotation.
- The whole study focused on smallholder farms. Yet, a multi-scale study including villages and landscapes could provide additional insights. For instance, one could capture the effects of water bodies or industrial activities in nutrient cycling. In turn, the multi-scale MFAs would provide the necessary indicator values to assess nutrient criticality not only at the smallholder farm level, but also at the village and landscape level.
- Material flows show qualities that are not the object of an MFA, yet these qualities might be of great interest in specific cases. For instance, as transport is an issue for the recycling of compost and dung, the material flow F 34 (compost, dung) should further be characterized with respect to distance from redistribution unit to primary production units, road type, availability of transport equipment, etc. Also of interest are questions related to gender: Who manages what flow?
- Energy and monetary flow analyses could answer further questions related to the quantity of energy saved by substituting mineral fertilizers with compost and dung and to the amount of money made available for recycling activities thanks to this same substitution. In the energy flow case, one should include energy embodied in mineral fertilizers, i.e., energy required to produce the mineral fertilizers. In the monetary flow case, one could investigate in scenarios the effect of altered subsidy schemes, as discussed in Section IV.d.

- A link between MFA results and geographic information systems (GIS) has the potential to yield spatially-explicit insights into regional nutrient flows and e.g., their drivers (Baccini and Brunner 2012). Concretely, MFA results would become an additional layer of GIS projects.

SECTION V – LIST OF PLANNED PUBLICATIONS

List of planned publications that will be based on the present work. Publications can be original research articles on ISI journals, written and oral contributions to international conferences, policy briefs, and so on.

- Material potentials for and indicators of sustainable smallholder farming systems: a demonstrative case study in South-western Burkina Faso. To be submitted to *Agriculture Ecosystems & Environment*

SECTION VI – ANNEXES

Annex 1: References

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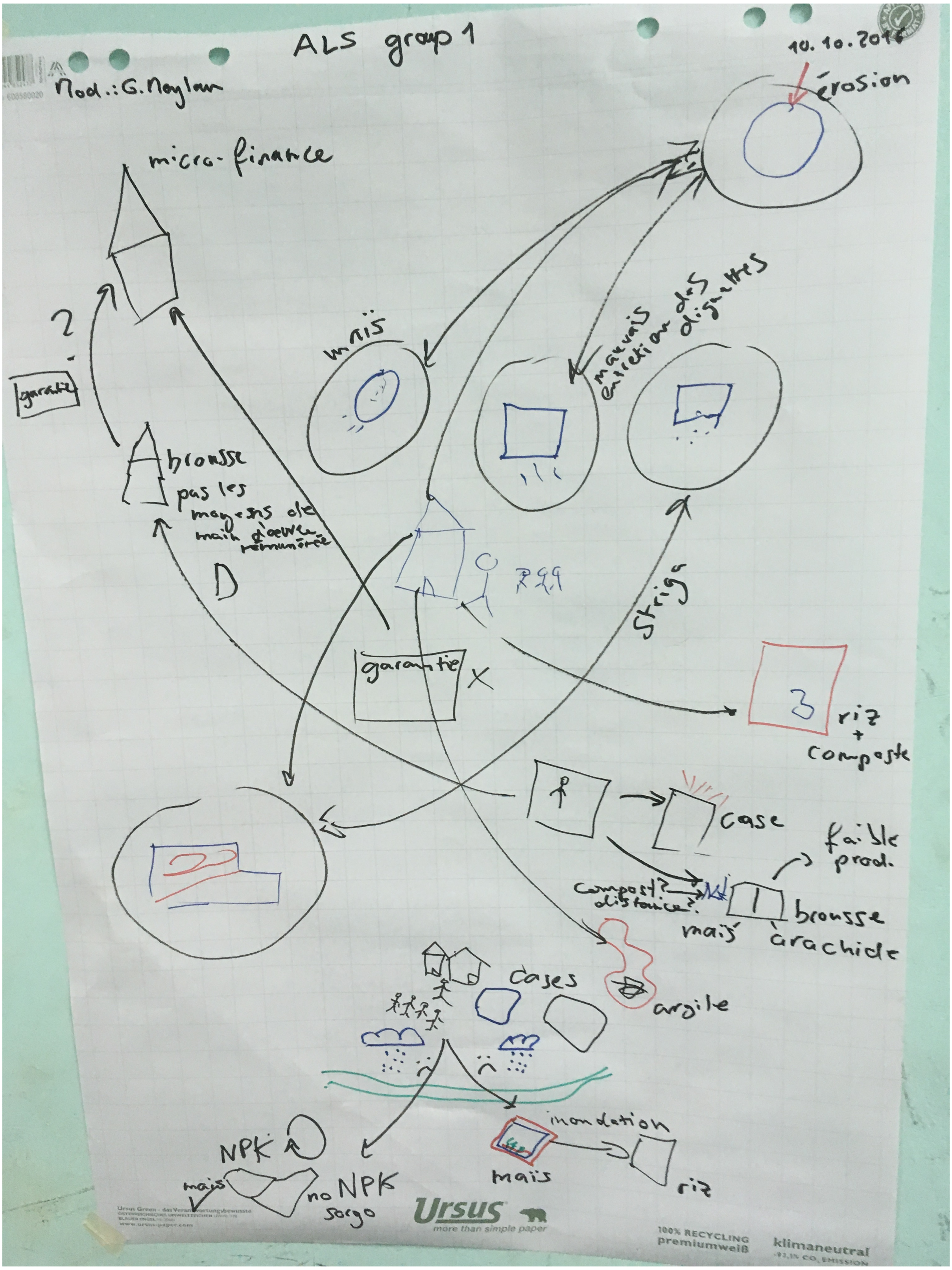
Annex 2: Status quo and scenario material flow analyses

15x2 STAN files. These files are readable with STAN software. At the current stage (until a journal paper of this work published), these files are available for uses for collaborative research only. Contact: Dr. Grégoire Meylan (g.meylan@usys.ethz.ch)

Annex 3: Rich pictures and improvements by farmers

Rich picture ALS group 1 (10.10.2016, moderation by Grégoire Meylan)

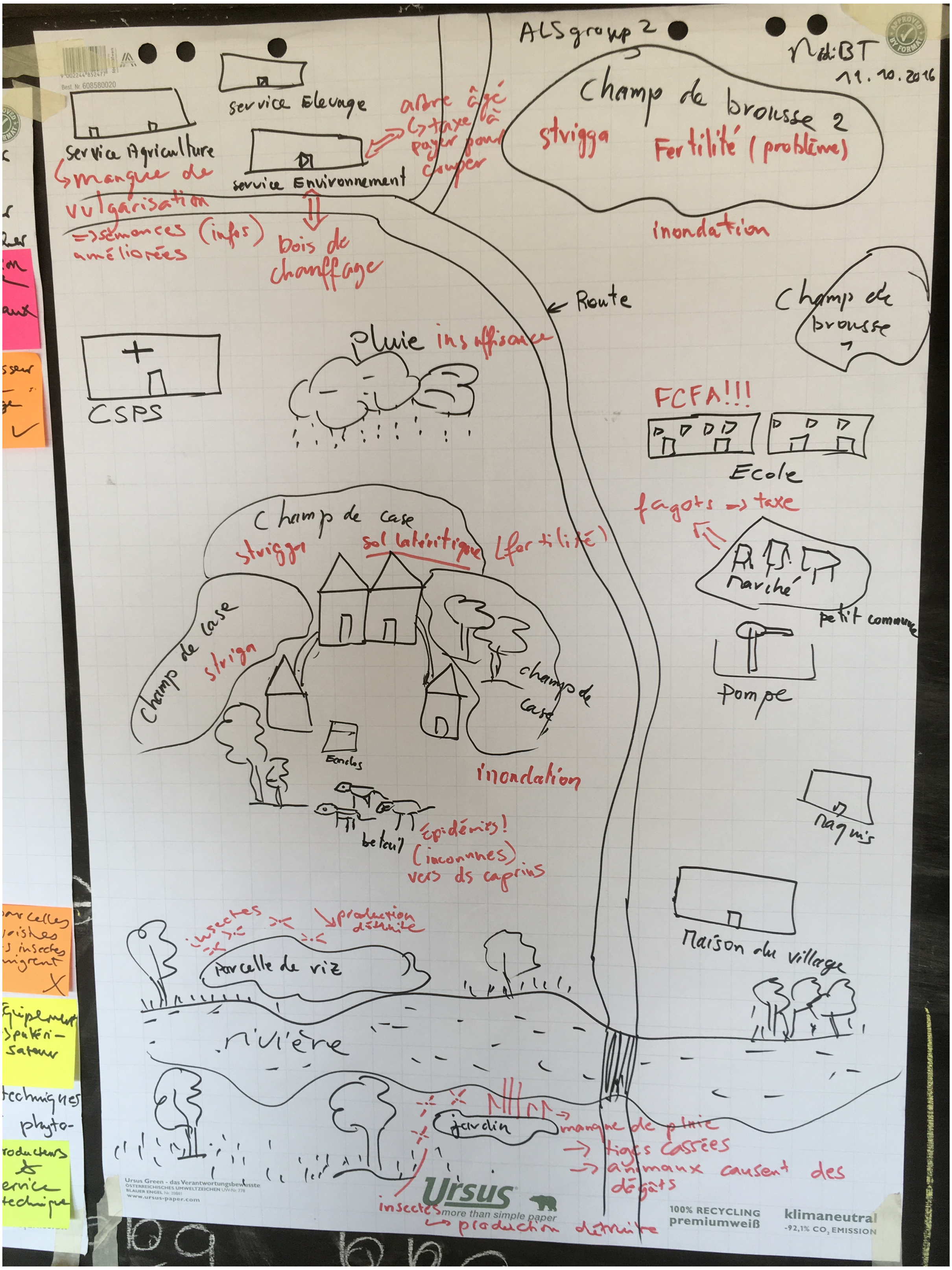


Improvements ALS group 1 (11.10.2016, moderation by Grégoire Meylan)

Purpose	Customers	Actors	Transformation process	Owners	Environmental constraints	Affected flow(s)
Fight erosion and keep nutrients	+ Famer, neighboring farmers (example) - Neighboring farmers (nutrient loss)	Farmer	Construct a low stone wall	Hunters	Labor, hill (source of rocks), cart	F38, P3
Enrich soil	+ Farmer, transport material rental firm, neighboring farmers (nutrient transfer)	Farmer	Transport compost and manure to remote plot	Farmer	Availability of financial resources, roads, labor (if road is to be constructed)	F34
Enrich soil, fight striga (witch weed)	+ Farmer, neighboring farmers (nutrient transfer)	Farmer	Enrich soil	Farmer	Labor availability	F04
Fight striga (witch weed)	+ Farmer	Farmer	Weed after rain	Farmer	Labor availability	F19, F21, F23, F24
Fight striga (witch weed)	+ Farmer	Farmer	Sow early	Animals (eating seeds)	Labor availability	
Keep spread fertilizers on plot, facilitate access	+ Farmer, neighboring farmers (physical benefits) - Neighboring farmers (nutrient loss)	Farmer grouping or farmer (if grouping not possible)	Better maintain little dykes	Fishers (damaging dykes), clogging through weeds	Availability and access to rocks, vehicles, equipment (wheelbarrow, pickaxe, shovel)	F38, P3

Facilitate access to credit for farmers	+ Farmer, neighboring villages (example) - Farmers failing to join grouping (exam), farmers not meeting terms (bitterness)	Core group (several groupings per village are possible), micro-finance institutions (support)	Create a grouping warranty fund	Farmers themselves if terms not met	Availability of own resources	

Rich picture ALS group 2 (11.10.2016, moderation by Boundia A. Thiombiano)

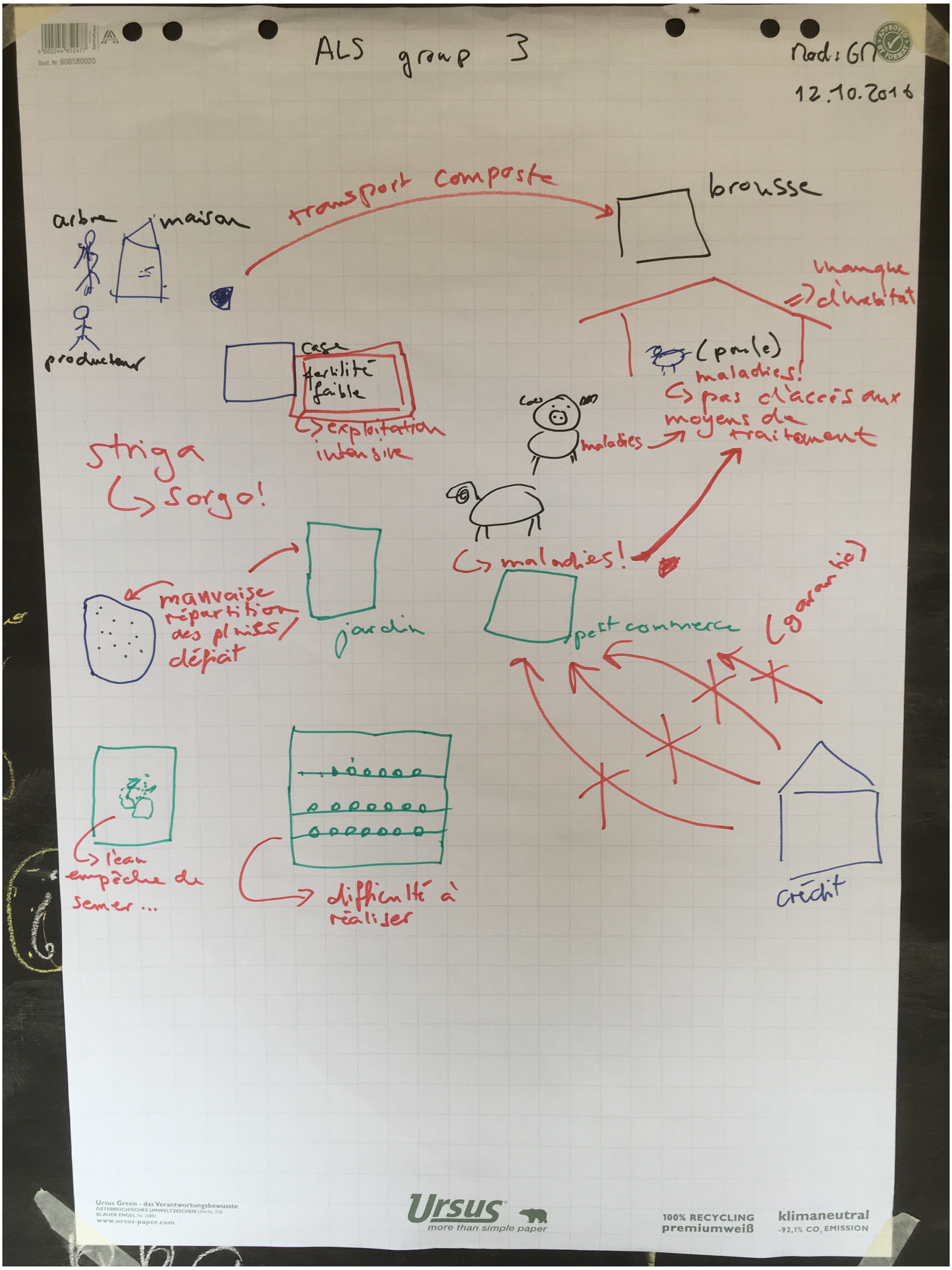


Improvements ALS group 2 (12.10.2016, moderation by Grégoire Meylan)

Purpose	Customers	Actors	Transformation process	Owners	Environmental constraints	Affected flow(s)
Increase soil fertility, fight striga (witch weed)	+ Farmer, family, neighboring farmers (example)	Farmer	Enrich soil	Farmer	Labor availability, information provided by Agriculture Service, equipment (e.g., cart, wheelbarrow, shovel, pick-axe)	F04
Increase production yield	+ Farmer	Agriculture Service, Farmer (responsible for sourcing)	Get better access to improved seeds (linked to previous)	Farmer	Availability of money, trust between Agriculture Service and farmer,	F04
Fight insects	+ farmer, consumers, traders (better products), phytosanitary industry - Neighboring farmers (migration of insects)	Farmer, Technical Service	Get better access to phytosanitary treatment	Famer	Products (chemical and natural), popularization and information, equipment (vaporizer)	F04
Fight flooding	+ Farmer, family, friends (gifts) - Dolo consumers (Dolo: local beer made from red sorghum)	Farmer, Agriculture Service (responsible for popularization)	Produce strict pluvial rice instead of sorgo	Market (buyers)	Sufficient rain, access to fertilizers, equipment for rice cultivation, labor, access to rice seeds	F04

Improve animal care, re-invest in farm	+ Farmer, consumers (higher product quality)	Farmer	Make livestock farming more profitable	Buyers (market prices)	Corral, feed, veterinary care (3 most important points)	F04 (except corral)
Protect against animals	+ Famer, trader (better products), fence supplier	Farmer and/or farmer grouping	Surround/protect market garden	Farmer	Pike, cement, wheelbarrow, shovel, sand, availability of money and labor	

Rich picture ALS group 3 (12.10.2016, moderation by Grégoire Meylan)



Improvements ALS group 3 (12.10.2016, moderation by Grégoire Meylan)

Purpose	Customers	Actors	Transformation process	Owners	Environmental constraints	Affected flow(s)
Keep nutrients on plot, keep soil humidity, fight soil erosion	+ Farmer, neighboring farmers (example)	Farmers (trained by who?)	Reinforce low stone walls	Farmer	Cart, pickaxe (for transport), week water streams	F38, P3
Maintain fertility of remote plot	+ Farmer	State or private project	Be trained in composting and acquire transport equipment	(State or private project is only expected once)	Awareness of state mechanisms	F34
Better distribute rain	+ Farmer, society	Farmer	Reforest	(State encourages action)	Equipment, trees	
Improve livestock health	+ Farmer, consumer	Veterinaries (visits)	Get better access to treatment against livestock diseases	Farmer	Market (non-saturated, i.e., good prices), drug costs (veterinary costs borne by State)	P4
Fight effects of water stagnancy	+ Farmer, traders, consumers	Farmer	Sow earlier	Animals (eating seeds)		

Fight striga (witch weed), increase soil fertility	+ Farmer, SOFITEX, Dolo producers/consumers	Farmer, SOFITEX (providing seeds and mineral fertilizers, purchasing harvest, providing income if surplus)	Rotate cotton and sorgo	SOFITEX (providing mineral fertilizers)	Small plot surface is sufficient	F04
Increase financial possibilities	+ Farmer, bank, friends, parents	Farmer grouping	Group financial capital to provide bank with warranty	Bank (in case of lack of liquidity)	Financial capital	

RESEARCH PROGRAM ON
Dryland Systems
CGIAR

The CGIAR Research Program on Dryland Systems aims to improve the lives of 1.6 billion people and mitigate land and resource degradation in 3 billion hectares covering the world's dry areas.

Dryland Systems engages in integrated agricultural systems research to address key socioeconomic and biophysical constraints that affect food security, equitable and sustainable land and natural resource management, and the livelihoods of poor and marginalized dryland communities. The program unifies eight CGIAR Centers and uses unique partnership platforms to bind together scientific research results with the skills and capacities of national agricultural research systems (NARS), advanced research institutes (ARIs), non-governmental and civil society organizations, the private sector, and other actors to test and develop practical innovative solutions for rural dryland communities.

The program is led by the International Center for Agricultural Research in the Dry Areas (ICARDA), a member of the CGIAR Consortium. CGIAR is a global agriculture research partnership for a food secure future.

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