The CoProdScope: an assessment and advisory tool for crop and livestock co-product management to intensify agroecology in agro-pastoral farms

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Summary

Farms in the savannah areas of Sub-Saharan Africa are largely based on agro-pastoral systems. They produce large quantities of crop co-products (CCP, i.e. straw, tops, stalks) and livestock co-products (LCP, i.e. faeces). However, only a small proportion of co-products are recovered to meet their needs for fodder, manure and mulch. Improving the recovery of co-products is an effective way to boost farm autonomy, productivity and long-term resilience. It also helps farmers adapt their practices as part of their agroecological transition. The CoProdScope (CPS) tool has been designed with a view to: 1) carrying out an annual review of CCP and LCP management at farm level in order to assess the proportion of unrecovered co-products, and to identify recovery potential (Review step); 2) co-designing a strategy with the farmer (Management Advisory step), with the aim of recovering CCP and LCP as fodder (storage and field grazing), manure (pit and pen manure), mulch (straws and stalks covering the soil) and for distribution to third parties. This paper describes how the CPS tool works, presents the review and management advisory stages, and outlines the potential digital development that would make the CPS suitable for field use by agricultural advisors.

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■ INTRODUCTION

In the savannahs of Sub-Saharan Africa, most farms are based on agro-pastoral systems (Séré and Steinfeld, 1996). With the rapid growth in the farming population, more land is being cultivated and livestock numbers are rising, along with the demand for fertilisers and animal feed (Chatel and Raton, 2018; Herrmann et al., 2020). Yet, the price of mineral fertilisers and industrial livestock feed is also going up (Giller et al., 2021). Cheaper alternatives are urgently needed to replace industrial inputs. These alternatives should also be able to meet farmers' needs and provide the necessary requirements for their farm activities, in terms of animal nutrition and soil organic matter.

Crop co-products (CCP, i.e. tops, straw, stalks) and livestock co-products (LCP, i.e. faeces) are produced in large quantities in agro-pastoral systems. They are raw materials that farmers can use for saving forages, producing manure or maintaining mulch on soil. Since crop-livestock synergies and co-products recycling are major factors for agroecology in West African agro-sylvo-pastoral systems (Vall et al., 2023), the tool will help farmers to increase recycling of their co-products and thus become more resilient in a context of high input prices and a lack of natural resources. This document describes the operating principles of the CPS tool, presents the review and advisory co-product stages and describes how the CPS can be used in the field by agricultural advisers.

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■ THE DESIGN AND THE USE OF THE CPS

How the CPS works and how to use it

The CPS is based on the interaction between an agricultural advisor and a farmer. By working together, they can compile (Figure 1): 1) a quantified review of the CCP and LCP management and conversion practices used to produce fodder, manure and mulch at farm level over the past year (N) (called Review stage); and 2) a quantified advisory for valuing CCP and LCP for the coming year (N+1) (called Advisory Management stage).

Ideally, the review should be carried out at the end of the dry season in year N, when the recovery cycle for year N's co-products is over. The Advisory should be jointly drawn up at the end of the rainy season in year N+1, when the farmer has a clearer idea of what the situation will be in the upcoming dry season (crop yields, animal births, availability of spontaneous pasture and water). There are few agricultural advisors in the savannah areas of Sub-Saharan Africa (Faure et al., 2019). To address this issue, the CPS was designed to provide a rapid review and advisory (around 2 hours/review and per advisory). Thus, it has tremendous potential in terms of agricultural outreach.

Numerous farm activities are involved in the production and valorisation of CCP and LCP, all year round (Figure 2a). Therefore, a significant amount of data collection is required to complete the CCP & LCP Review. When completed, the review reveals the shortfall between what the farm produces and what it actually needs in terms of fodder, manure and mulch. The CPS can then help co-design a strategy with the farmer. It generates a CCP & LCP Advisory to improve the valorisation of co-products (Figure 2b).

The CPS currently runs on Microsoft® Excel®. It is comprised of 12 worksheets, many of which are interconnected, to provide an accurate picture of the stages involved in the production and use of co-products (Figure 3): Introductory Sheets (1.1 and 1.2) explain how the CPS works and how it is organised; Sheet 2 provides parameters for the Input Sheet equations; Sheet 3 contains farm data, such as the farmer's identity, labour and equipment; Sheets 4.0, 4.1, 4.2, 4.3 and 4.4 relate to the Review process; Sheets 5.0, 5.1 and 5.2 relate to the co-design of the Advisory process.

We present the CPS and how to use it for compiling a review and an advisory, by providing data from a fictitious farm in the following sections (Vall and Zoungrana, 2023). Vall and Zoungrana (2023) deposited a dataset in Dataverse, showing the tool in its current version 2.0 on Excel, using data from a fictitious farm as an example.

Preliminary phase: introducing the tool, entering the parameters and farm characterisation

Introducing the CPS

Sheets 1.1 and 1.2 explain the aims of the CPS, how it is organised and how to use it. Sheet 1.1 sets out the two main goals: the review and the advisory. Sheet 1.2 outlines the overall organisation and provides details of the different steps, their content, as well as the links between the sheets.

CPS parametrization

To configure the CPS, several parameters are required. They are listed on Sheet 2:

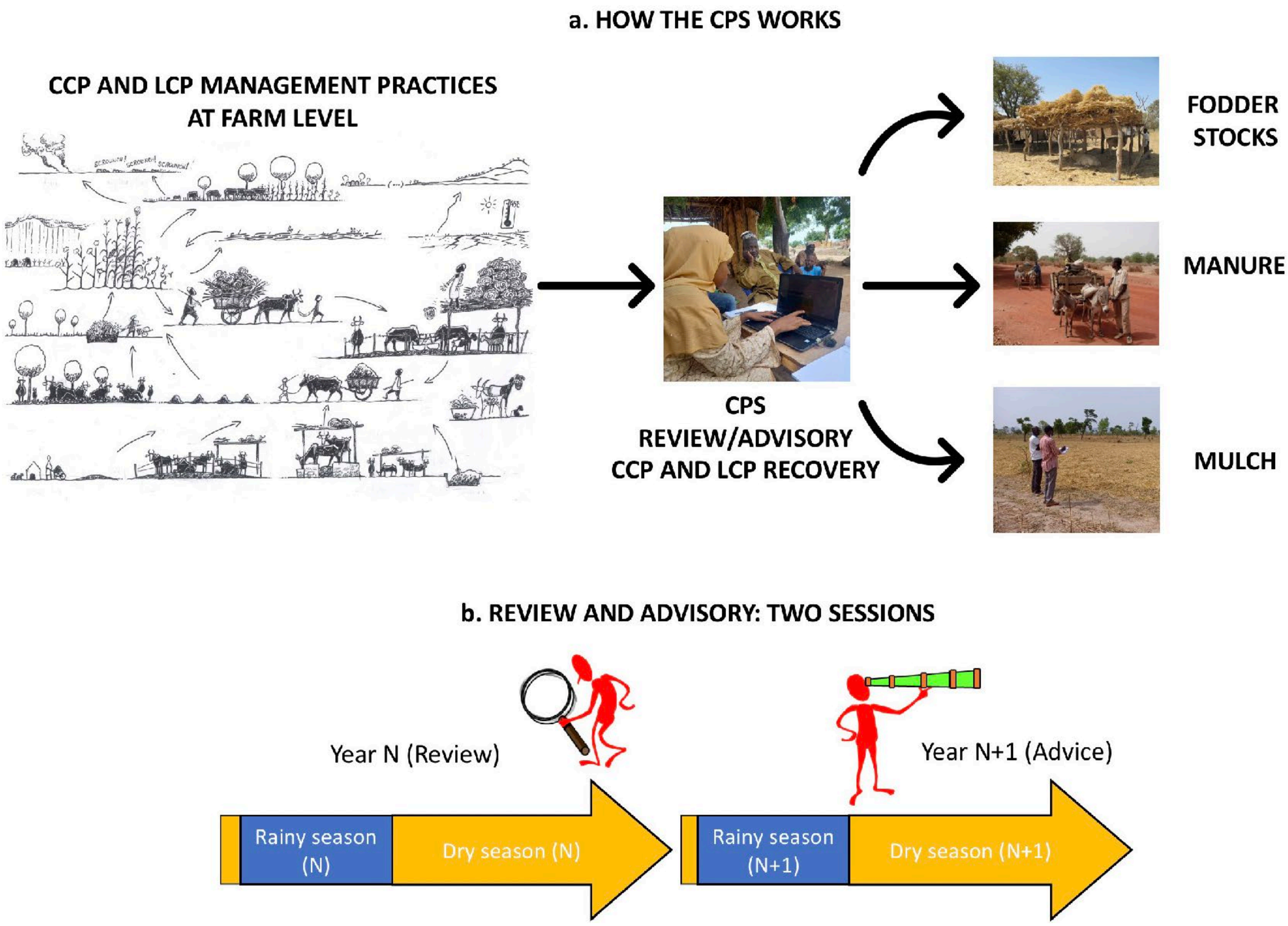


Figure 1: How the CPS works /// Comment fonctionne le CPS

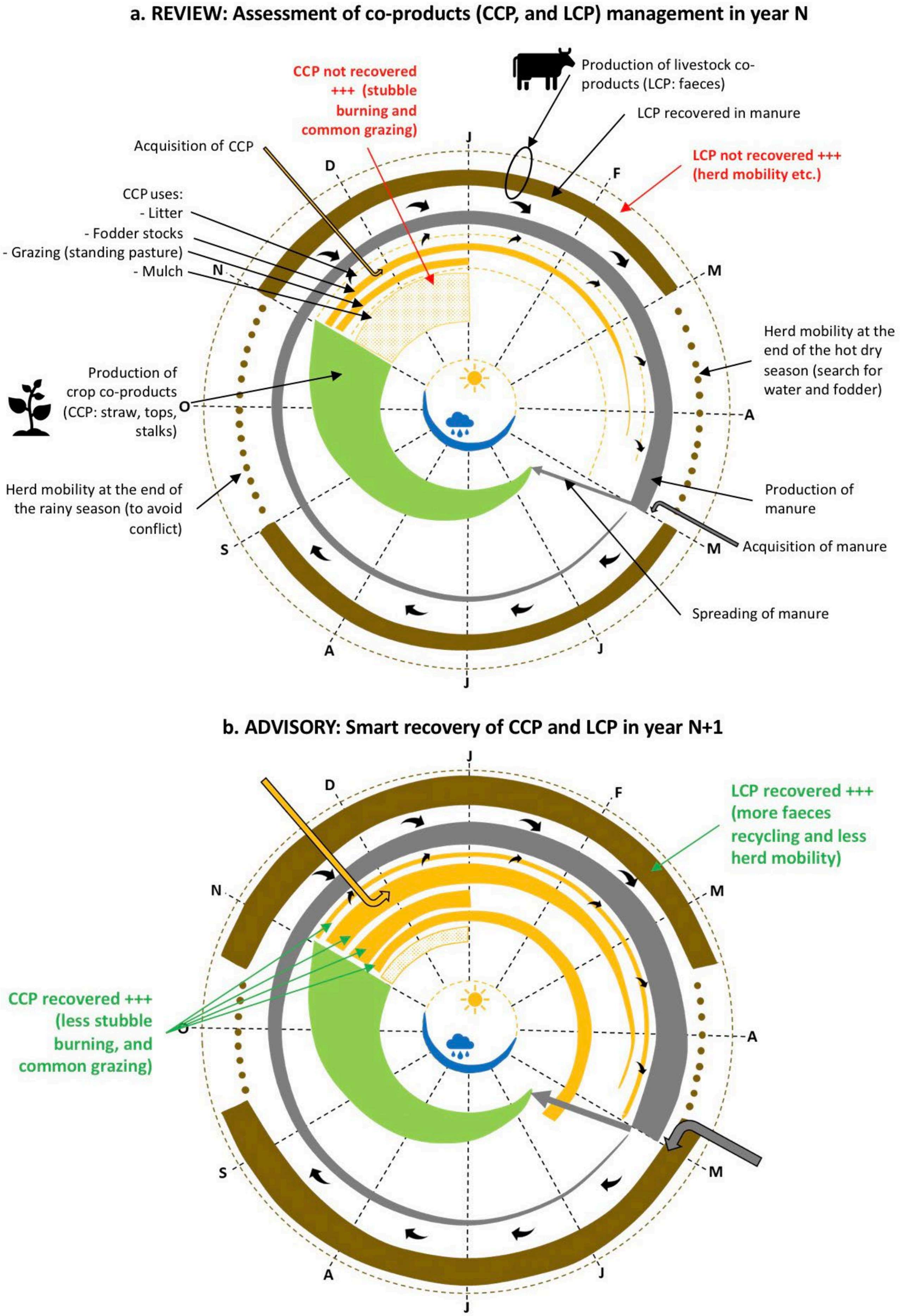


Figure 2: Life cycle of co-products (CCP and LCP) during the review year (a) and during the advisory year (b) /// *Cycle de vie des co-produits (CCP et LCP), pendant l'année de bilan (a) et pendant l'année de conseil (b)*

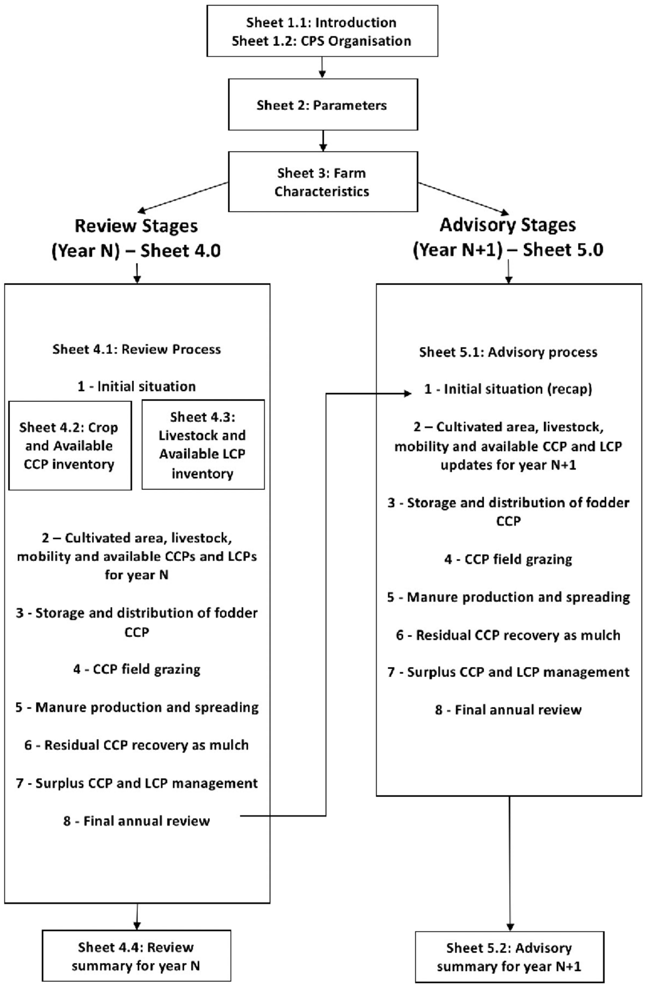


Figure 3: The general structure of the CPS and the stages involved in preparing the Review and Advisory for the on-farm management of crop and livestock co-products (CCP and LCP) /// *Structure générale du CPS et étapes d'élaboration du Bilan et du Conseil de gestion des co-produits de culture (CCP) et d'élevage (LCP) à l'échelle de l'exploitation agricole*

- The farm orientation (crop, livestock or mixed farming) according to the typology proposed by Vall et al., 2017;
- The duration of the 3 seasons (rainy, cool dry and hot dry) in months and days, as defined by the agricultural advisor and the farmer;
- Crops: grain/CCP ratios taken from the literature (Pieri, 1989; Dugué, 1999; Autfray et al., 2012 and UICN, 2015) and unpublished reports; typical crop yields based on statements from a sample of 15 farmers;
- Livestock: herd composition (cattle, sheep and goats) in Tropical Livestock Units (1 TLU = 1 adult weighing 250 kg), according to age and sex; and specific data for cattle (suckling, dairy, draught, fattening cattle);
- Fodder intake: voluntary feed intake at pasture (6.25 kg Dry Matter (DM)/TLU/day; Guérin et al., 1985); portion of fodder in hot dry season (5 kgDM/TLU/day, according to our recommendations); coarse fodder rejection rate (10%) and quality fodder rejection rate (5%), as suggested by the authors;
- Production of solid manure (LCP), which is estimated at 1,000 kgDM/TLU/year (Landais and Guérin, 1992);
- The transport capacities (bales carried, rickshaw, motorbike, dumper, small and large flatbed cart, motorised tricycle, trailer) for CCP (cotton stalks, coarse fodder, quality fodder) and manure, based on our field measurements;
- Manure: mature manure/raw material recovery rate (60% in pits and barns, 40% in pens and heaps, as suggested by the authors); percentage of CCP (60%) and LCP (40%) in quality manure (Berger, 1996); recommended annual input (2,500 kgDM/ha/year; Berger, 1996);
- Ground cover (mulch): we created a 6-level visual assessment grid for the mulch density of four crops (cotton, maize, sorghum/millet and rice) with conversion ratios for each score (in kgDM/ha). We suggested the following mulch density levels: low 2 tDM/ha; medium 4 tDM/ha; and high 6 tDM/ha.

Farm characterization

In Sheet 3, the agricultural advisor enters the data on the farmer's identity, labour, equipment and tools for handling, storing and collecting co-products.

The data for the fictitious farm are as follows: 9 farming assets (8 family workers and 1 employee); 1 small flatbed cart; 1 motorised tricycle; 2 fodder sheds; 1 manure pit.

Stages involved in the review and advisory processes for co-product management

From this point onwards, eight stages are involved in compiling the review and advisory, respectively (Figure 3). While the sequences are similar, different approaches are used for each process. For the review, the agricultural advisor asks the farmer about what was achieved in year N. For the advisory, the farmer and the advisor discuss and agree on what should be done in the coming year, N+1.

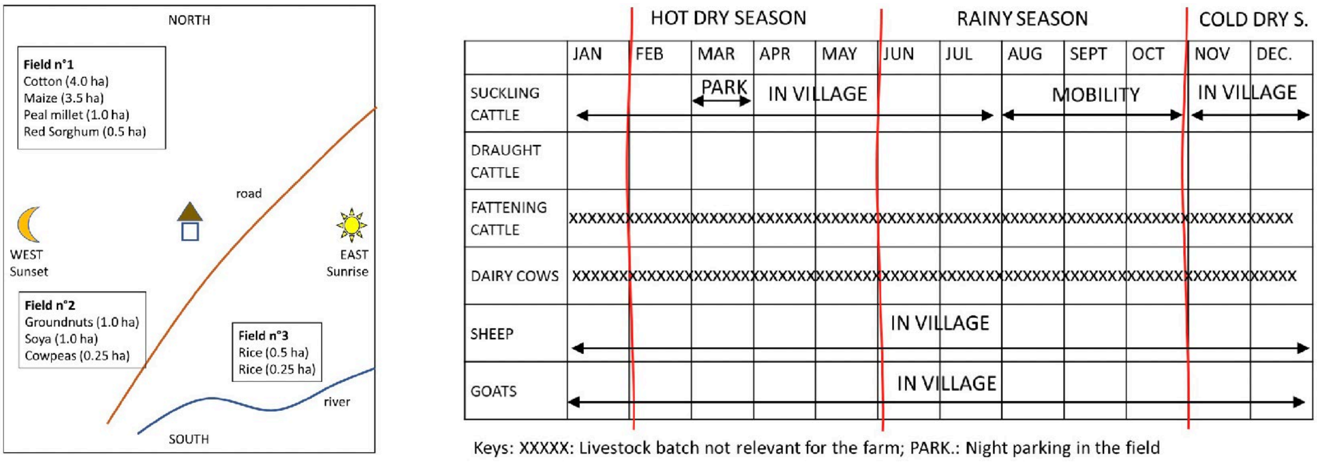
Below, we present a step-by-step guide to the review and advisory processes. In this paper, we focus primarily on the interactions between the agricultural advisor and the farmer at each stage. The results for the key CPS calculations are illustrated using data from the fictitious farm for each stage. The CPS interface and equations are not discussed here because it is beyond the scope of this paper. For further information on interfaces and equations used in the CPS, the reader can refer to Vall and Zoungrana (2023).

Stage 1: Initial situation

For the review, Sheets 4.2 and 4.3 allow the advisor to carry out: crop inventories per plot and field; livestock inventories per livestock batch, such as suckling cattle, dairy cows, draught cattle, feeder cattle, sheep and goats; and available CCP/LCP inventories for each of these categories. The advisor uses a cropping plan and a livestock batch presence schedule, which are printed on paper (Figure 4). We illustrate how to use the CPS using a fictitious farm as an example. This farm has 3 cultivated fields covering 12 ha, planted with cotton (4 ha), maize (3.5 ha), red sorghum (0.5 ha), pearl millet (1 ha), rice (0.75 ha), groundnuts (1 ha), cowpea (0.25 ha), and soya (1 ha). The farm livestock are equivalent to 14 TLU, with suckling cows (8 TLU), draught cattle (4 TLU), sheep (1 TLU) and goats (1 TLU). All the livestock batches remain in the village throughout the year, except the suckling cattle, which are on the move for 3 months during the hot dry season. This batch is also penned in the field at night for a month during the hot dry season (Figure 4).

Stage 1 allows the agricultural advisor and the farmer to determine the farm's agro-pastoral orientation (crops, livestock or mixed farming), according to the typology proposed by Vall and al. (2017). Our fictitious farm is mixed (12 ha and 14 TLU).

Stage 1 is also useful for assessing the farm's potential capacity to provide fodder, manure and mulch requirements. Thus, it is possible to identify the farm's strengths and weaknesses. In the case of the fictitious farm, 100% of fodder requirements, 72% of manure requirements and 84% of mulch requirements are met. As it only produces 72% of its manure requirements, lack of manure is considered its main weakness.



(a) Cropping plan (b) Livestock batch presence schedule

Figure 4: Cropping plan and livestock batch presence schedule for the fictitious farm in year N (Review) /// *Plan des champs cultivés et calendrier de présence des lots d'animaux de l'exploitation fictive au cours de l'année N (Bilan)*

Stage 1 of the advisory section simply recalls Year N's review (Table 1). It serves as a reminder to the farmer of the strengths and weaknesses of his/her co-product management practices in Year N before going on to co-design a co-product recovery strategy.

Stage 2: Cultivated area, livestock mobility and available CCP and LCP

For the review, the agricultural advisor indicates the available crop and livestock co-products to the farmer:

- Data on cultivated areas and available CCP comes from Sheet 4.2 and is automatically displayed, crop by crop. On the fictitious farm, the available CCP include: 5.4 tDM of cotton stalks, 15.8 tDM of coarse fodder (cereal straw) and 1.4 tDM of quality fodder (legume tops) (Table 1).
- Livestock data is provided on Sheet 4.3. However, to determine the volume of recoverable LCP and the amount of LCP lost through livestock mobility per season and per livestock batch, the advisor must record: livestock arrivals and departures over the last 12 months; the number of days of mobility per season and per livestock batch. On the fictitious farm, recoverable LCP amounts to 7.9 tDM across all batches and the LCP lost through mobility totals 1.3 tDM (Table 1).

For the advisory section, the farmer and agricultural advisor update the data on crops (acreage and available CCP) and livestock (livestock numbers, arrivals/departures, mobility schedule and available LCP) for year N+1. For the fictitious farm, the CPS provides the following estimates for available CCP and LCP: for CCP, 2.8 tDM of cotton stalks, 18.9 tDM of coarse fodder and 4.1 tDM of quality fodder; and for LCP, 7.3 tDM of recoverable LCP and no LCP losses as a result of mobility (Table 1).

Stage 3: Storage and distribution of fodder CCP

For the review, the advisor asks the farmer for details about the quantities of coarse and quality fodder stored, produced both on farm or bought in. Quantities are expressed as the number of journeys and the transport used. For the fictitious farm, the review shows stocks of 340 kgDM of quality fodder and 4.4 tDM of coarse fodder, all sourced from the farm.

For the advisory section, the advisor first reminds the farmer of the farm's fodder requirements for the hot dry season (9.0 tDM in the case of the fictitious farm). Then they jointly calculate the quantities of CCP (coarse and quality) to be stored (available stocks produced on farm or bought in) to cover requirements, considering the farmer's means of transport. On the fictitious farm, the farmer plans to use a small flatbed cart and the stock levels forecast are 4 tDM of coarse fodder and 4 tDM of quality fodder, all produced on farm.

Lastly, for the review and advisory phases, the farmer specifies the fodder rations and the number of days of distribution for each livestock batch and type of fodder (coarse/quality). However, as a number of studies have shown (Sib et al., 2017 and Sodré et al., 2022), farmers often struggle to provide accurate estimates because they do not record the quantities distributed. As a result, the diet data provided is indicative.

Stage 4: CCP field grazing

For the review, the advisor collects details from the farmer about the number of CCP grazing days and the daily number of CCP grazing hours for each livestock batch and for both coarse and quality fodder. Adding up this data across all batches gives the quantity of grazed CCP for both types of fodder. On the fictitious farm, the amounts of quality and coarse fodder are 135 and 378 kgDM, respectively.

For the advisory section, the advisor reminds the farmer of any available CCP that remains in the cultivated area. They recommend using them as quickly as possible during the cold dry season, before neighbouring livestock and transhumant herders pass through. For each type of CCP (coarse and quality fodder) and for each livestock batch, the advisor and farmer agree on the number of grazing days and grazing hours per day. For the fictitious farm and for all batches, the field grazing forecast corresponds to grazing intakes of 5.0 tDM of coarse fodder (since all the quality fodder was stored).

However, CPS tests have shown that farmers either forget or find it difficult to quantify the future CCP intake in the field. Thus, the data provided is indicative.

When considering CCP storage/distribution in a trough plus CCP field grazing, the fictitious farm shows a theoretical improvement in CCP fodder recovery between the review for year N and the advisory in year N+1: from 4.8 to 9.1 tDM for coarse fodder; and from 0.5 to 4.0 tDM for quality fodder (Table 1).

Stage 5: Manure production and spreading

For the review and advisory steps, the agricultural advisor reminds the farmer of the farm's manure requirements. In the case of the fictitious farm, the figures are: 30 tDM for year N and 32 tDM for year N+1. At this stage, the quantities of residual CCP after storage and field grazing are known, in addition to the amount of recoverable LCP.

During the review and the advisory process, the advisor and farmer discuss penning livestock at night in order to produce pen manure to spread in the field. If the farmer has used this practice in year N (Review) or wishes to do so in year N+1 (Advisory), then by indicating the duration of penning (number of nights), field by field (3 in our fictitious example) and per livestock batch (suckling cattle in year N, suckling and draught cattle in year N+1), the CPS can determine how much pen manure deposited in each field. Thus, the pen manure deposited on a single field amounted to 125 kgDM in year N (Review) compared with a forecast of 621 kgDM in year N+1 (Advisory) due to a longer penning period and the addition of draught cattle.

Then, the review and advisory phases focus on on-farm manure production. If the farmer produced this type of manure in year N (Review) or intends to do so in year N+1 (Advisory), then the CPS determines how much manure was produced per site (pens, barns/sheds, pits, heaps). The type of manure is specified, for example, manure or pen manure. 'Manure' is produced if CCP (litter) is added to LCP, while 'pen manure' is mainly made up of LCP, with no added CCP, except for left-over fodder. The CPS records any potential litter input (cotton stalks, coarse fodder). On the fictitious farm, the amount of home-produced manure was 3.6 tDM of pen manure in year N (Review). It increased in the projections for year N+1 (Advisory) to 5.8 tDM of quality manure due to the addition of litter (cotton stalks and cereal straw).

On the fictitious farm, the farmer did not use CCP as litter in year N (Review). However, he intends to use 2.5 tDM of cotton stalks and 1.7 tDM of coarse CCP (straw) as litter in year N+1 (Advisory). This change has a significant impact on manure production, which increases from 3.7 tDM of pen manure with low value as fertiliser in year N (Review) to 9.7 tDM of high-quality manure forecast for year N+1 (Advisory) (Table 1).

Then, total manure production is compared with the farm's requirements. At this point, if there is a shortfall, off-farm manure is included. When requirements are not met (which is the case for the fictitious farm), the agricultural advisor asks the farmer at the review stage whether manure has been acquired. At the advisory stage, the advisor asks whether the farmer intends to obtain off-farm manure to make up for the shortfall. The CPS records the amount of off-farm manure obtained. On the fictitious farm, no off-farm manure was acquired in year N (Review) despite a very low level of production: 13% of total manure requirements. However, the farmer planned to acquire 3 tDM in year N+1 (Advisory), which improved the ratio to 31% (Table 1).

Lastly, for the review and advisory phases, the advisor and farmer discuss how much manure will be spread per field. For the fictitious farm, 2.7 tDM of manure was spread on a single field in year N (Review), compared to a forecast of 6.9 and 2.3 tDM on two fields in year N+1 (Advisory). This represents a clear improvement (+240% compared to year N).

Stage 6: Residual CCP recovery as mulch

This stage considers the recovery of CCP that is not stored, grazed or burnt, but left in the fields as mulch.

For the review and advisory phases, the agricultural advisor and farmer proceed on a field-by-field basis (3 fields in the case of the fictitious farm). For legume plots, the CPS considers that all CCP have been collected at the end of the dry season and, therefore, that the soil is bare. In other words, on the fictitious farm, 0 kgDM/ha of mulch is applied to field 3, which is used for legume crops. For a given field under cotton and/or cereals, the advisor gives the farmer an assessment of soil cover density using a grid of mulch density. It includes all four crops (cotton, maize, sorghum/millet and rice). The farmer is then asked to indicate which figure matches the soil cover condition rating (on a scale of 1 to 6) at the end of the dry season, for each crop grown in the field. The CPS converts the ratings into mulch densities (kgDM/ha) and determines the average mulch density per field. On the fictitious farm, a rating was applied to fields 1 and 2. For year N (Review), the CPS calculated mulch densities of 0.9 and 0.7 tDM/ha for both fields. The densities were increased to 1.8 and 1.3 kgDM/ha for year N+1 because the farmer planned protective and monitoring measures. Although this is an improvement, ground cover remains poor; a mulch density of <2 tDM/ha is considered to be low.

Using a visual assessment grid for soil cover density works well. However, the current CPS grid is rudimentary and needs improving.

Stage 7: Surplus CCP and LCP management

Stage 7 concerns the sale to third parties of CCP and LCP residues, which are not recovered by the farm. It constitutes the last form of co-product recovery provided for in the CPS.

For the review and advisory phases, the agricultural advisor asks the farmer what proportion of CCP (cotton stalks, coarse and quality fodder) and manure was disposed of to third parties in year N (Review) and is expected to be disposed of in year N+1 (Advisory). For the advisory phase, when disposals are expected, the CPS determines the quantity in terms of number of journeys for a given mode of transport. This provides practical information, which is useful to the farmer.

Stage 8: Summary

Stage 8 provides summaries of the review and advisory phases using the same format. The first section gives an overview of the activity linked to CCP and LCP recovery. The second section provides a general assessment of farm requirements for fodder, manure and mulch. Figures for the fictitious farm are shown in Table 1.

Between year N (Review) and year N+1 (Advisory), the following can be observed for the fictitious farm:

- Available CCP and LCP numbers may increase (coarse and quality fodder) or decrease (cotton stalks, LCP), depending on changes in cultivated areas and livestock numbers, as well as crop yields and livestock mobility;
- Recovery rates have improved for: i) CCP (coarse and quality), which is recovered as fodder (stored or grazed in the field); ii) CCP recovered as litter (cotton stalks and coarse fodder); coarse fodder recovered as mulch; LCP recovered as pit manure (good quality manure with added litter);
- An overall decline in LCP recovered as pen manure (low quality manure with no added litter);
- Less CCP and LCP were unrecovered or lost as a result of herd mobility.

Therefore, for the fictitious farm, there is a clear improvement in the recovery of CCP and LCP between year N (Review) and year N+1 (Advisory). As a result, the farm is closer to meeting its needs for fodder (the percentage rose from 35% to 83%), manure (from 13% to 31%) and mulch (from 0% to 7%).

The review and advisory conclusions are summarised on an A4 sheet, which means the farmer has a record of the findings from the review and advisory phases.

■ DISCUSSION

A tool adapted to the needs of farmers and agricultural advisors

The CPS incorporates key farming practices to manage co-products at farm level. Thus, it meets the genuine needs of farmers, in line with the recommendations of Abdulai (2022) and Abdulai et al. (2023), who have studied the factors that determine the success of digital advisory tools for African agriculture.

Table 1: Overview of CCP and LCP recovery and coverage of requirements for fodder, manure and mulch for year N (Review) and year N+1 (Advisory) on the fictitious farm /// *Vue d'ensemble de la récupération des CCP et LCP et de la couverture des besoins de l'exploitation fictive en fourrage, fumier et paillis pour l'année N (Bilan) et l'année N+1 (Conseil).*

Variables	Review Year N	Advisory Year N+1
1. CCP and LCP recovery		
CCP		
Cotton stalks		
Available (kgDM)	5,445	2,856
Recovered as fodder (kgDM)	0	0
Recovered as manure (kgDM)	0	2,550
Recovered as mulch (kgDM)	0	61
Recovered (%)	0	91
Unrecovered or disposed of to third parties (kgDM)	5,445	245
Coarse fodder		
Available (kgDM)	15,840	18,907
Recovered as fodder (kgDM)	4,798	9,129
Recovered as manure (kgDM)	0	1,700
Recovered as mulch (kgDM)	0	1,616
Recovered (%)	30	66
Unrecovered or disposed of to third parties (kgDM)	11,042	6,462
Quality fodder		
Available (kgDM)	1,462	4,140
Recovered as fodder (kgDM)	475	4,080
Recovered as manure (kgDM)	0	0
Recovered as mulch (kgDM)	0	0
Recovered (%)	32	99
Unrecovered or disposed of to third parties (kgDM)	987	60
LCP		
Available (kgDM)	7,929	7,363
Recovered as manure (kgDM)	0	5,804
Recovered as dry manure from field (kgDM)	312	1,553
Recovered as dry manure from pen (kgDM)	6,210	0
Recovered (%)	83	100
Lost through mobility (kgDM)	1,407	6
2. Coverage of farm needs		
Fodder		
Fodder needs for the dry season (kgDM)	15,264	15,858
CCP grazed and stored for the dry season (kgDM)	5,273	13,209
Fodder needs covered by CCP (%)	35	83
Manure		
Manure needs (kgDM)	30,000	31,875
Produced and acquired manure (kgDM)	3,756	9,788
Manure needs covered by CCP and LCP (%)	13	31
Mulch		
Light mulch requirements 2 tDM/ha (kgDM)	24,000	25,500
CCP recovered as mulch (kgDM)	0	1,677
Mulch needs covered by CCP (%)	0	7

The CPS is user-friendly. It simplifies the representation of co-product management at farm level and encourages dialogue between the farmer and the advisor for the purposes of drafting a review and an advisory. It generates valuable outputs in a short space of time, as recommended in the study by Oyinbo et al. (2020).

The CPS has no competitor tools to date. The closest known advisory tools are designed for the management of nutrients in Nigeria (Oyinbo et al., 2020), and for fuels produced from crop and industrial residues in Togo (Beguedou et al., 2023).

The CPS makes it possible to tailor advice to the farmer's situation. This gives it an advantage over impersonal advisory services based on technical data sheets (Blanchard et al., 2011).

A participative tool

By including a review stage and an advisory stage, the CPS genuinely encourages a joint approach, whereby a forecast (the advisory) can be drawn up with the farmer, based on the actual situation (the review). The modelling tools used in farm advisory services, which allow for farmer involvement, do not usually include both these stages. As a result, the modelling process must be repeated to produce a snapshot of the situation at different points in time (Semporé et al., 2016; Sib et al., 2018; Le Gal et al., 2022). The CPS has a chronological structure and uses an interactive approach, including: a survey of the actual situation, as part of the review; and discussions that lead to a jointly drafted forecast at the advisory stage. The CPS gives farmers real support by taking into account their practices, views, needs and expectations. Each stage involves discussions, which generate concrete recommendations. Therefore, in theory, the targets set with the farmer are realistic, consistent with the farmer's resources (labour, equipment) and correspond to his/her needs.

However, there is room for improvement. For example, it would be interesting if an improved version of the tool let the farmer prioritise how they use co-products (for fodder, manure or mulch) in the advisory section. In a situation where the quantities of co-products are often limited, the advisory may vary, depending on the priorities for the use of co-products.

More precise and adaptable parameters to improve CPS simulations

Given the lack of documentation in the scientific literature on most parameters relating to co-products, we have established a number of benchmark references. These are based on field measurements, farmer surveys, data from unpublished reports and on our own agricultural knowledge. At the moment, we clearly do not have enough academic or empirical data on co-product references. Indeed, the methodical development of co-product references is a research priority that could make a valuable contribution to agroecology, an approach based on farming interaction, and recycling practices (Debray et al., 2019; Wezel et al., 2020; Vall et al., 2023). Thus, agroecology places more emphasis on co-products than is the case in conventional farming systems.

In future improved versions of the CPS, the user (farmer) should be able to choose the parameter values that are best suited to their local situation. We are currently working on an improved version that includes this option.

CPS development prospects

Today, digital tools are increasingly used in agriculture to provide information, benchmarks and answers to farmers' concerns. Several studies show that digital tools have the capacity to: improve access to information (Fabregas et al., 2019; Ortiz-Crespo et al., 2020;

Witteveen et al., 2017); help advisor/farmer interactions (Baumüller, 2018; Munthali et al., 2018; Omulo and Kumeh, 2020); allow farmers to provide feedback on recommendations (Lacoste et al., 2022; van Etten, 2011). According to Alexandre (2023), who studied the potential of 11 digital agricultural services that were tested in Burkina Faso, the legitimacy, success and sustainability of digital tools depend on three factors: i) provision of personalised information; ii) interaction between agricultural advisor and farmer; and iii) feedback from farmers on the advice provided.

To make the CPS more user-friendly in rural areas, we plan to incorporate these factors into our IT development project. The current CPS prototype runs on a computer-based Microsoft® Excel® spreadsheet, which makes it difficult for an advisor to use in the field. Our aim is to develop two interlinked versions of the CPS: 1) a 'desktop' Internet version connected to a data storage server; 2) an Android-based mobile version that can run on a mobile phone or tablet and be linked to the Internet version. Agricultural advisors will use the mobile version to collect data in the field. The desktop version will be used primarily to manage the data collected (archiving, storage and retrieval for further analysis). This will allow agricultural advisors to work without the need for an Internet connection, a real advantage given the poor Internet connections in rural areas in many Sub-Saharan African countries (for example, Burkina Faso, Alexandre, 2023).

■ CONCLUSION

The CPS tool is designed to help individual farmers improve CCP and LCP recovery at farm level. It provides the farmer with a review of the overall management of CCP and LCP on their farm for the past year. In addition, it helps the agricultural advisor draft a strategy with the farmer (Advisory) to recover CCP and LCP as fodder, manure and mulch for the coming year. The farm's requirements and capacities (labour and equipment) are also taken into account.

At present, the CPS provides a quantitative assessment of CCP and LCP recovery. In addition, it calculates the farm's capacity to provide fodder, manure and mulch to meet its needs. The tool uses a large number of parameters. The accuracy of the CPS calculations could be improved if the parameters were better referenced. The current CPS does not assess the impacts that improved co-product management has on crop and livestock performance or on the farm's economic performance. These elements provide interesting avenues for further research.

While the current CPS operates at farm level, co-product users are often external to the farm. In future, a tool for co-product management could be developed with a broader scope to include data on the main stakeholders that use co-products and on the rules for sharing access, as well as space. A sophisticated tool of this kind would not only help farmers, it would also reflect the territorial nature of co-product management and make an important contribution to agroecological transition.

Data availability statement

Data used in this article are publicly available as open data via the Cirad dataverse, at the following URL: https://doi.org/10.18167/DVN1/X3GRDT

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Conflicts of interests

The authors declare that there is no conflict of interest.

Author contributions statement

SRZ and EV created the CoProdScope (CPS) tool and drafted the article presenting it. SRZ, DS and ALP tested the tool in a real life environment. SRZ and EV wrote the revised versions of the article and SO, OS and VMCBY reviewed the article.

REFERENCES

Abdulai A.R., 2022. Toward digitalization futures in smallholder farming systems in Sub-Sahara Africa: A social practice proposal. *Front. Sustain. Food Syst.*, **6**: 866331, doi: 10.3389/fsufs.2022.866331

Abdulai A.R., Krishna Bahadur K.C., Fraser E., 2023. What factors influence the likelihood of rural farmer participation in digital agricultural services? experience from smallholder digitalization in Northern Ghana. *Outlook Agric.*, **52** (1): 5766, doi: 10.1177/00307270221144641

Alexandre C., 2023. Les technologies numériques : des outils au potentiel inexploité pour faciliter les apprentissages des agriculteurs. Une étude de onze services numériques de conseil agricole au Burkina Faso. *Innovations*, **70** (1): 4981, doi: 10.3917/inno.pr2.0139

Autfray P., Sissoko F., Falconnier G., Ba A., Dugué P., 2012. Usages des résidus de récolte et gestion intégrée de la fertilité des sols dans les systèmes de polyculture élevage : étude de cas au Mali-Sud. *Cah. Agric.*, **21** (4): 225-234, doi: 10.1684/agr.2012.0568

Baumüller H., 2018. The Little We Know: An Exploratory Literature Review on the Utility of Mobile Phone-Enabled Services for Smallholder Farmers. *J. Int. Dev.*, **30** (1): 134–154, doi: 10.1002/jid.3314

Beguedou E., Narra S., Afrakoma Armoo E., Agboka K., Kongnine Damgou M., 2023. E-Technology Enabled Sourcing of Alternative Fuels to Create a Fair-Trade Circular Economy for Sustainable Energy in Togo. *Energies*, **16** (9): 3679, doi: 10.3390/en16093679

Berger M., 1996. Fumure organique : des techniques améliorées pour une agriculture durable. *Agric. Dev.* **1**: 3746, https://agritrop.cirad.fr/388322/

Blanchard M., Koutou M., Vall E., Bognini S., 2011. Comment évaluer un processus innovant ? Cas de l'amélioration quantitative et qualitative de la fumure organique au champ. *Rev. Elev. Med. Vet. Pays Trop.*, **64** (14): 6172, doi: 10.19182/remvt.10115

Chatel C., Raton G., 2018., Population, peuplement et agriculture en Afrique subsaharienne : vers un changement de paradigme. *Espaces Populations Sociétés, Centre National de la Recherche Scientifique*, 12 p.

Debray V., Wezel A., Lambert-Derkimba A., Roesch K., Lieblein G., Francis C.A., 2019. Agroecological practices for climate change adaptation in semiarid and subhumid Africa. *Agroecol. Sustain. Food Syst.*, **43** (4): 429-456, doi: 10.1080/21683565.2018.1509166

Dugué P., 1999. Utilisation de la biomasse végétale et de la fumure animale : impacts sur l'évolution de la fertilité des terres en zone de savanes. Etude de cas au Nord-Cameroun et essai de généralisation : rapport final de l'ATP « Flux de biomasse et gestion de la fertilité à l'échelle du terroir ». CIRAD-TERA n 57-99. CIRAD, Montpellier, France, https://agritrop.cirad.fr/6798/

Fabregas R., Kremer M., Schilbach F., 2019. Realizing the potential of digital development: The case of agricultural advice. *Science*, **366** (6471): eaay3038, doi: 10.1126/science.aay3038

Faure G., Dugué P., Fongang Fouepe G.H., 2019. Diversité des formes de conseil agricole en Afrique de l'Ouest et du Centre. *Grain de Sel,* **77**: 6-7

Giller K.E., Delaune T., Silva J.V., van Wijk M., Hammond J., Descheemaeker K., van de Ven G., et al., 2021. Small farms and development in Sub-Saharan Africa: Farming for food, for income or for lack of better options? *Food Sec.*, **13** (6): 1431–1454, doi: 10.1007/s12571-021-01209-0

Guérin H., Sall C., Friot D., Ahokpe B., Ndoye A., Ba T.M., Faye A., et al., 1985. Ebauche d'une méthodologie de diagnostic de l'alimentation des ruminants domestiques dans un système agropastoral : l'exemple de Thyssé-kaymor - Sonkorong au Sénégal. Communication N° 18 présentée le 10-13 septembre 1985 au séminaire Relations Agriculture Elevage DSA-CIRAD, Montpellier, France, https://agritrop.cirad.fr/474986/1/ID474986.pdf

Herrmann S.M., Brandt M., Rasmussen K., Fensholt R., 2020. Accelerating land cover change in West Africa over four decades as population pressure increased. *Commun. Earth Environ.*, **1** (1): 110, doi: 10.1038/s43247-020-00053-y

Lacoste M., Cook S., McNee M., Gale D., Ingram J., Bellon-Maurel V., MacMillan T., et al., 2022. On-Farm Experimentation to transform global agriculture. *Nat. Food*, **3** (1): 1118, doi: 10.1038/s43016-021-00424-4

Landais É., Guérin H., 1992. Systèmes d'élevage et transferts de fertilité dans la zone des savanes africaines. *Cah. Agric.*, **1** (4): 225-238

Le Gal P.Y., Andrieu N., Bruelle G., Dugué P., Monteil C., Moulin C.H., Penot E., et al, 2022. Modelling mixed crop-livestock farms for supporting farmers' strategic reflections: The CLIFS approach. *Computers Electron. Agric.*, **192**: 13, doi: 10.1016/j.compag.2021.106570

Munthali N., Leeuwis C., van Paassen A., Lie R., Asare R., van Lammeren R., Schut M., 2018. Innovation intermediation in a digital age: Comparing public and private new-ICT platforms for agricultural extension in Ghana. *NJAS–Wageningen J. Life Sci.*, **86–87** (1): 64–76, doi: 10.1016/j.njas.2018.05.001

Omulo G., Kumeh E.M., 2020. Farmer-to-farmer digital network as a strategy to strengthen agricultural performance in Kenya: A research note on 'Wefarm' platform. *Technol. Forecast. Soc. Change*, **158**: 120120, doi: 10.1016/j.techfore.2020.120120

Ortiz-CrespoB., Steinke J., Quirós C., van de Gevel J., Siringo H., Mgimiloko G., van Etten J., 2020. User-centred design of a digital advisory service: enhancing public agricultural extension for sustainable intensification in Tanzania. *Inter. J. Agric. Sustain.*, 117, doi: 10.1080/14735903.2020.1720474

Oyinbo O., Chamberlin J., Maertens M., 2020. Design of Digital Agricultural Extension Tools: Perspectives from Extension Agents in Nigeria. *J. Agric. Econ.*, **71** (3): 798815, doi: 10.1111/1477-9552.12371

Pieri C., 1989. Fertilité des terres de savanes. Bilan de trente ans de recherche et de développement agricoles au Sud du Sahara. CIRAD-IRAT, Montpellier, France, 452 p. https://agritrop.cirad.fr/375686/

Semporé A.W., Andrieu N., Le Gal P.Y., Nacro H.B., Sedogo M.P., 2016. Supporting better crop-livestock integration on small-scale West African farms: a simulation-based approach. *Agroecol. Sustain. Food Syst.*, **40** 1: 3–23, doi: 10.1080/21683565.2015.1089966

Séré C., Steinfeld H. 1996. World livestock production systems. FAO Animal Production and Health Paper 127. Rome, Italy: FAO. https://www.fao.org/DOCREP/004/W0027E/W0027E00.HTM

Sib O., Bougouma-Yameogo V.M.C., Blanchard M., Gonzalez-Garcia E., Vall E., 2017. Production laitière à l'ouest du Burkina Faso dans un contexte d'émergence de laiteries : diversité des pratiques d'élevage et propositions d'amélioration. *Rev. Elev. Med. Vet. Pays Trop.*, **70** (3) : 8191, doi: 10.19182/remvt.31521

Sib O., Bougouma-Yameogo V.M.C., Blanchard M., Gonzalez-Garcia E., Vall E., 2018. Prodlait : un outil permettant d'ajuster l'alimentation des vaches pour atteindre un objectif de production fixe par l'éleveur. *Agron. Afric.*, **30** (2): 157168, doi: 10.4314/aga.v30i2

Sodré É., Moulin C.H., Ouédraogo S., Gnanda I.B., Vall E., 2022. Améliorer les pratiques d'alimentation des vaches traites en saison sèche, un levier pour augmenter le revenu des éleveurs laitiers extensifs au Burkina Faso. *Cah. Agric.*, **31** (12): 9, doi: 10.1051/cagri/2022006

Tittonell P., Gérard B., Erenstein O., 2015. Tradeoffs around crop residue biomass in smallholder crop-livestock systems–What's next? *Agric. Syst.*, **134**: 119-128. doi: 10.1016/j.agsy.2015.02.003

UICN-Burkina Faso, 2015. Evaluation de l'état général des ressources pastorales dans la Région de l'Est du Burkina Faso. UICN, Ouagadougou, Burkina Faso, 118 p.

Vall E., Diallo M.A., Fako Ouattara B., 2015. De nouvelles règles foncières pour un usage plus agroécologique des territoires en Afrique de l'Ouest. *Sci. Eaux Territ.*, **16** (1): 52-57, doi: 10.3917/set.016.0052

Vall E., Marre-Cast L., Kamgang H.J., 2017. Chemins d'intensification et durabilité des exploitations de polyculture-élevage en Afrique subsaharienne : contribution de l'association agriculture-élevage. *Cah. Agric.*, **26** (2): 25006, doi: 10.1051/cagri/2017011

Vall E, Orounladji B. M., Berre B, Assouma M. H., Dabiré D., Sanogo S., Sib O., 2023. Crop-livestock synergies and by-products recycling: major factors for agroecology in West African agro-sylvo-pastoral systems. *Agron. Sustain. Dev.* **43** (70): 1-16, doi.org/10.1007/s13593-023-00908-6

Vall E., Zoungrana R., 2023. An illustrated case study of the CoProdScope tool with the data of a fictitious farm of Burkina Faso. Dataset deposit in Dataverse', CIRAD Dataverse, doi: 10.18167/DVN1/X3GRDT

Van Etten J., 2011. Crowdsourcing Crop Improvement in Sub-Saharan Africa: A Proposal for a Scalable and Inclusive Approach to Food Security. *IDS Bulletin*, **42** (4): 102110, doi: 10.1111/j.1759-5436.2011. 00240.x

Wezel A., Gemmill Herren B., Bezner Kerr R., Barrios E., Rodrigues Gonçalves A.L., Sinclair F., 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agron. Sustain. Dev.* **40**: 40, doi: 10.1007/s13593-020-00646-z

Witteveen L., Lie R., Goris M., Ingram V., 2017. Design and development of a digital farmer field school. Experiences with a digital learning environment for cocoa production and certification in Sierra Leone. *Telemat. Informat.*, **34** (8): 16731684, doi: 10.1016/j.tele.2017.07.013

Résumé

Zoungrana S.R., Saadatou D., Sib O., Loabé Pahimi A., Ouédraogo S., Bougouma-Yaméogo V.M.C., Vall E. Le CoProdScope : un outil de bilan et de conseil pour la gestion des co-produits de culture et d'élevage pour une intensification agroécologique des exploitations agropastorales

Les exploitations agricoles des zones de savane de l'Afrique subsaharienne sont principalement agro-pastorales. Elles produisent de grandes quantités de co-produits de culture (CCP, c'est-à-dire paille, fanes, tiges) et de co-produits d'élevage (LCP, c'est-à-dire fèces). Toutefois, seule une petite partie des co-produits est récupérée pour répondre aux besoins en fourrage, en fumier et en paillis. L'amélioration de la valorisation des co-produits est un moyen efficace de renforcer l'autonomie, la productivité et la résilience des exploitations sur le long terme. Elle permet également aux agriculteurs d'adapter leurs pratiques dans le cadre de leur transition agroécologique. L'outil CoProdScope (CPS) a été conçu dans le but de : 1) réaliser un bilan annuel de la gestion des CCP et LCP au niveau de l'exploitation afin d'évaluer la part de co-produits non valorisés, et d'identifier le potentiel de valorisation (étape Bilan) ; 2) co-concevoir une stratégie avec l'agriculteur (étape Conseil en gestion), dans le but de valoriser les CCP et LCP sous forme de fourrage (stockage et pâturage au champ), de matière organique (fumier en fosse et en enclos), de paillis (couverture des résidus de culture) et de cession de surplus à des animaux tiers. Ce document décrit les principes de fonctionnement de l'outil CPS, présente les étapes de bilan et de conseil de gestion, et trace les perspectives de développement numérique qui permettront au CPS d'être utilisé sur le terrain par les conseillers agricoles.

Mots-clés : Fourrage, gestion du fumier, système d'aide à la décision, recyclage des matières organiques, fumier organique, Afrique subsaharienne

Resumen

Zoungrana S.R., Saadatou D., Sib O., Loabé Pahimi A., Ouédraogo S., Bougouma-Yaméogo V.M.C., Vall E. CoProdScope: una herramienta de evaluación y asesoramiento en la gestión de los co-productos agrícolas y ganaderos para la mejora agroecológica de las explotaciones agropecuarias

Las explotaciones agrícolas de las zonas de sabana del África subsahariana son principalmente agropecuarias. Producen grandes cantidades de co-productos agrícolas (CCP, es decir, paja, brozas, tallos...) y co-productos de ganadería (LCP, es decir, heces). Sin embargo, solo una pequeña parte de los co-productos se recupera para responder a las necesidades de forraje, estiércol y pajote. La mejora de la valorización de los co-productos es un medio eficaz para reforzar la autonomía, la productividad y la resiliencia de las explotaciones a largo plazo. También permite que los agricultores adapten las prácticas en el marco de su transición agroecológica. La herramienta CoProdScope (CPS) ha sido concebida con el objetivo de: 1) realizar un balance anual de la gestión de los CCP y LCP de la explotación para evaluar la parte de co-productos no valorizados e identificar el potencial de valorización (etapa de evaluación); 2) codiseñar una estrategia con el agricultor (etapa de asesoramiento en la gestión), con el objetivo de valorizar las CCP y LCP en forma de forraje (almacenaje y pasto en el campo), de materia orgánica (estiércol en fosa y en corral), de pajote (cobertura de residuos de cultivo) y de cesión de excedente a animales de terceros. Este documento describe los principios de funcionamiento de la herramienta CPS; presenta las etapas de evaluación y de asesoramiento en la gestión, y dibuja las perspectivas de desarrollo digital que permitirán que los consejeros agrícolas utilicen el CPS sobre el terreno.

Palabras clave: Forrajes, gestión del estiércol, sistemas de apoyo a las decisions, reciclaje orgánico, mantillos orgánicos, Africa subsahariana