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Recycling crop and livestock co-products on agro-pastoral farms for the agroecological transition: more than 60% potentially recoverable in western Burkina Faso

Sombénéwendé Rasmata Zoungrana [(1)], Souleymane Ouedraogo [(1)], Ollo Sib [(2)], Valérie M. C. Bougouma-Yameogo [(3)], Tionyélé Fayama [(1)], Kalifa Coulibaly [(4)], David Berre [(5)], Mohamed Habibou Assouma [(2)], Éric Vall [(6)]

[(1)] INERA, Station de Farako-Bâ, 01 BP 910, Bobo-Dioulasso 01 (Burkina Faso). E-mail: dianezoungrana175@gmail.com
[(2)] CIRAD, UMR SELMET, Bobo-Dioulasso (Burkina Faso) – SELMET, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier (France).
[(3)] Université Nazi BONI, Institut de développement rural, Laboratoire des Systèmes naturels, Agrosystèmes et de l'Ingénierie de l'Environnement, Bobo-Dioulasso (Burkina Faso).
[(4)] Université Nazi BONI, Institut de développement rural, Laboratoire d'Étude et de Recherche sur la Fertilité du Sol, Bobo-Dioulasso (Burkina Faso).
[(5)] CIRAD, UPR AIDA, F-34398 Montpellier (France) – AIDA, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier (France).
[(6)] CIRAD, UMR SELMET, F-34398 Montpellier (France) – SELMET, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier (France).

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Description of the subject. Considering the increasing price of animal feeds and synthetic fertilizers, agro-pastoral farmers of Western Africa, in Burkina Faso in particular, try to increase the use of Crops Co-Products (CCP: straw, tops, stalks) and Livestocks Co-Products (LCP: faeces) to feed animals and fertilize cultivated fields, however face challenges to do so.
Objectives. Our objectives were to characterize the management and recycling practices of CCP and LCP at the farm level and to assess their contribution to the coverage of forage and manure needs.
Method. Data collected by survey on 60 agro-pastoral farms in six villages in western Burkina Faso. On-farm management practices of CCP and LCP characterized by eight variables. Flows of CCP and LCP characterized at three levels: farm, crop and livestock units, and type of co-product management system.
Results. Out of the ~21 tons of CCP available per farm, 23% are recycled as forage, and 77% are not or scarcely recovered by farms. Out of the ~24 tons of LCP available per farm, 40% are recovered for use as manure, 60% are scattered off-farm during grazing and mobility. Co-products recycling covers only 16% of farm needs in forage and manure.
Conclusions. Co-products are poorly recycled, and their level of recovery depends on farm equipment, manpower and herd mobility. Facing this challenge, we are developing a farm-level co-products recycling/advisory tool to support farmers in the agroecological transition.
Keywords. Integrated crop-livestock systems, by-products, efficiency, agroecology, Sub-Saharan Africa.

Recyclage des co-produits végétaux et animaux dans les exploitations agropastorales pour la transition agroécologique : plus de 60 % potentiellement valorisables dans l'ouest du Burkina Faso
Description du sujet. Face à l'augmentation du prix des aliments pour animaux et des engrais de synthèse, les agriculteurs agro-pastoraux d'Afrique de l'Ouest et du Burkina Faso en particulier, tentent d'augmenter l'utilisation des Co-Produits des Cultures (CCP : paille, fanes, tiges) et des Co-Produits des Animaux d'élevage (CPA : fèces) pour nourrir les animaux et fertiliser les champs cultivés, mais ils sont confrontés à des difficultés pour y parvenir.
Objectifs. Caractériser à l'échelle de l'exploitation les pratiques de gestion et de recyclage des CCP et CPA et évaluer leur contribution à la couverture des besoins en fourrages et en fumure.

Méthode. Données collectées par enquête sur 60 exploitations agro-pastorales de six villages de l'Ouest du Burkina Faso. Pratiques de gestion des CCP et CPA caractérisées par huit variables. Flux de valorisation des CCP et CPA caractérisés à trois niveaux : exploitation, par atelier de cultures et d'élevage, et par type de système de gestion des co-produits.
Résultats. Sur les ~21 tonnes de CCP disponibles par exploitation, 23 % sont recyclés en fourrage, et 77 % ne sont pas ou peu valorisés par les exploitations. Sur les 24 tonnes de CPA disponibles par exploitation, 40 % sont récupérés pour être utilisés comme fumier organique, 60 % sont dispersés hors de l'exploitation pendant le pâturage et la mobilité. Le recyclage des co-produits ne couvre que 16 % des besoins des exploitations en fourrage et en fumure organique.
Conclusions. Les co-produits sont peu valorisés et leur niveau de récupération dépend de l'équipement agricole, de la main-d'œuvre et de la mobilité des troupeaux. Face à cette insuffisance, nous développons un outil de bilan/conseil en recyclage des co-produits à l'échelle de l'exploitation pour soutenir les agriculteurs dans la transition agroécologique.
Mots-clés. Systèmes de culture et d'élevage intégrés, sous-produits, efficacité, agroécologie, Afrique subsaharienne.

1. INTRODUCTION

Today, in Sub-Saharan Africa, and particularly in the villages of western Burkina Faso, strong land pressure leads to intense competition for arable and grazing land (Herrmann et al., 2020). Fallowing is being replaced by continuous cropping (Gaiser et al., 2011). The areas available for grazing can no longer support the entire herd throughout the year, and some farmers prefer to move part of their herd rather than change their breeding habits (Dongmo et al., 2012a). The intense exploitation of natural resources leads to damages on biodiversity and ecosystems' health (Midgley & Bond, 2015). In addition, competition over these resources often escalates into violent conflicts between land users (Turner et al., 2011). As a result, agropastoralists struggle to maintain farmland fertility and feed their livestock (Thorton & Herrero, 2015). Faced with declining soil fertility and decreasing quality and quantity of fodder resources, agropastoralists purchase mineral fertilizers and livestock feed (Kelly et al., 2003). But these agro-industrial inputs are becoming unaffordable for most agropastoralists whose spending power is very limited (Giller et al., 2021). Besides, they do not provide a sustainable solution since ruminants need forage (Inra, 2018) and soils require organic matter (Bayu et al., 2005).

In this context, crop-livestock integration has long been identified as an appropriate model of sustainable intensification for farms simultaneously engaged in both activities (Landais & Lhoste, 1990; Herrero et al., 2010). And today, in a perspective of agro-ecological transition, such a model maximizing interactions between crops and livestock at farm level is considered as a model to be promoted in West African savannah regions in order to support this transition by recycling and reducing the use of inputs (Debray et al., 2019).

Crop-livestock integration aims to make better use of Crops Co-Products (CCP: cereal straw, legume tops, cotton [*Gossypium* sp.] stalks) and solid Livestock Co-Products (LCP: dung) generated on the farm, in the form of forage, manure and mulch. As the price of mineral fertilizer and feed increases, and arable and pasture land becomes more inaccessible, CCP and LCP become increasingly valuable. Yet several studies suggest that farm-level recovery rates remain low overall (Dongmo et al., 2012b: < 10% of potential recovered in northern Cameroon; Blanchard et al., 2013: ~40% of available CCP and LCP recovered in southern Mali), though without providing detailed information on the conditions and quantities recycled of CCP and LCP. This private management of co-product flows at the farm scale coexists with collective management of co-product flows at the village scale (Assogba et al., 2023). Considering the increasing land pressure, agro-pastoral farmers are in a more and more challenging situation to benefit from the co-products generated by their crops and their herds. We chose to conduct our study at the farm level to highlight this situation.

Our study therefore aims to explain the recycling of CCP and LCP at the level of agro-pastoral farms over a full agricultural cycle (12 months) through:
– a quantified inventory of the production and acquisition of CCP and LCP per farm;
– an identification of the different types of recycling of CCP and LCP;
– an assessment of the proportion of CCP and LCP lost and/or little or not used by the farm.

The study concludes with recommendations for improving farm-level CCP and LCP recycling in order to make these agro-pastoral systems more resilient and sustainable.

2. MATERIALS AND METHODS

2.1. Study area

The study was carried out in six villages selected by the FAIR Sahel project, which funded this work, located in Western Burkina Faso, Léna and Béréba. The six villages were selected due to the presence of diversified agro-pastoral systems in terms of crops and livestock, and their use of crop-livestock interaction practices of varying intensity (Vall et al., 2017; Berre et al., 2022).

The county of Léna (Houet province) is located 50 km from Bobo-Dioulasso and covers an area of 561 km². It has a population of 25,000 inhabitants spread over 14 villages including Bodialédaga, Yabasso and Konzo where the study was conducted. The county of Béréba (Tuy province) is located 115 km from Bobo-Dioulasso and spans an area of 569 km². It has 31,000 inhabitants spread over 29 villages, including Béréba, Lofikaoun and Bankoni where the study was carried out (**Figure 1**).

2.2. Sampling of surveyed farms and survey questionnaire

The 60 farms selected for the study were chosen randomly from a sample of 188 farms of the six selected villages. This sample of 188 farms was constructed considering the cultivated area, the cattle herd, and the equipment (transport, fodder storage, manure production) of the farm, in order to have farms presenting the full range of values of these criteria.

The reference period chosen to study CCP and LCP recycling practices was June 2020 to May 2021, *i.e.* a full year (from production of biomass in rainy season to complete use this biomass at the end of the following dry season). We proceed with one-step survey, at the end of the reference period with a retrospective questionnaire to appraise recycling practices along one year. Thus, the farm surveys were carried out from June 2021 to August 2021. The questionnaire included the following items:

– farmer identity;
– farm land characteristics (by field: area, location);
– farm equipment and buildings;
– crops inventory (by species) and management (by cultivated plot: cultivated area [ha]; grain production [kg]; terms of use of co-products [stored as fodder, grazed by the farm's livestock; grazed by other livestock, sold, burnt, in % of CCP available]);
– livestock inventory (by species and age, considering entries and exits over the year) and management (by livestock production unit and by season: location [mobility, village], housing, nourishing [grazing, fodder and feeds distribution], waste recovery);
– CCP recycling equipment and practices (in sheds, hay barns, etc.);

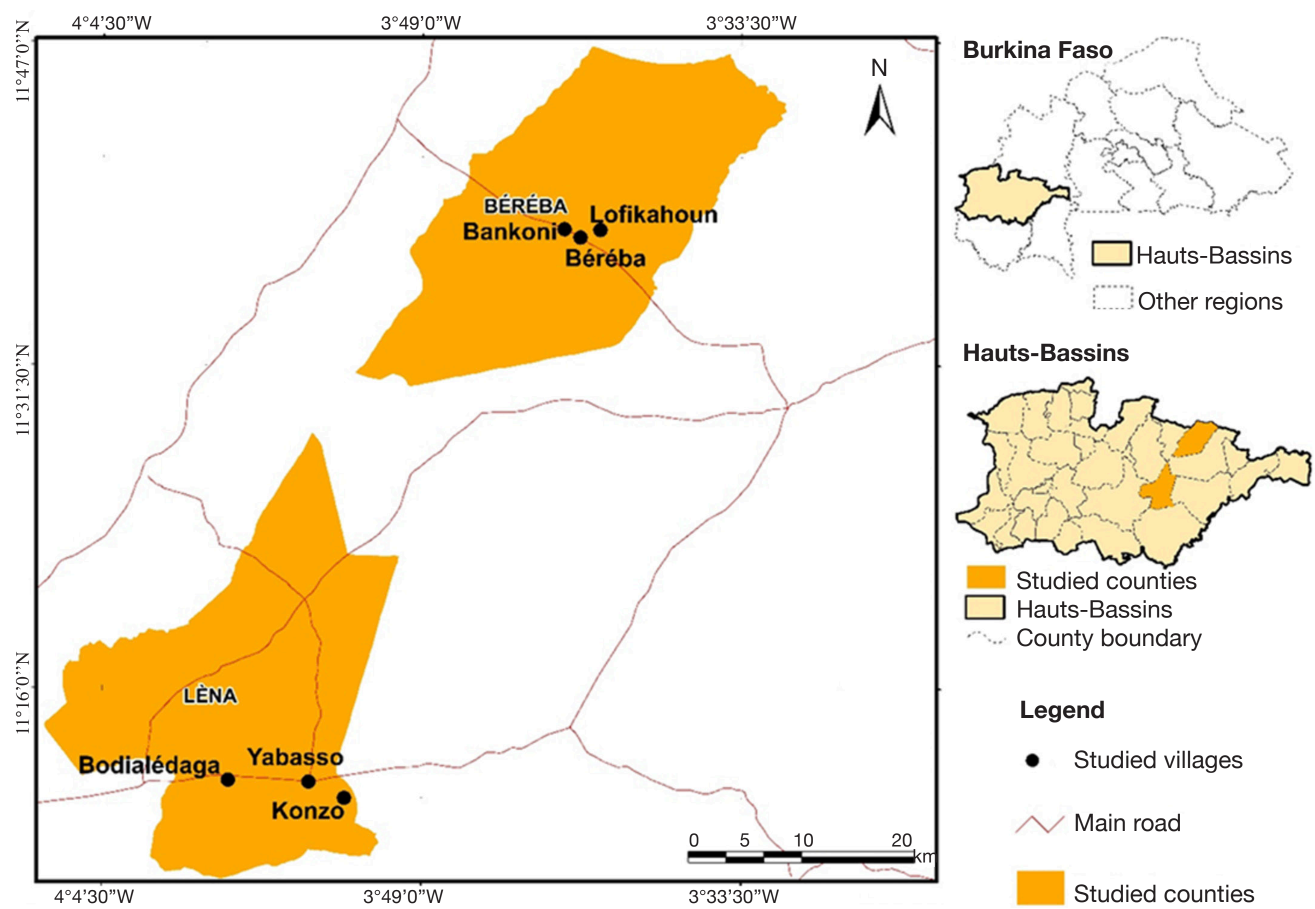

Figure 1. Study area — *Zone d'étude.*

Source: Base Nationale de Données Topographiques (BNDT), 2014.

– LCP recycling equipment and practices (in stalls, livestock pens, manure pits, and on the fields).

2.3. Flowchart and variables used for analyzing CCP and LCP recovery

The flowchart used to analyze farm-level CCP and LCP production and outcome is shown in **figure 2**. In this diagram, green arrows refer to CCP and LCP recovered by the farm and red arrows refer to CCP and LCP scarcely or no recovered by the farm. Note that CCP used for mulch (*i.e.*: CCP neither grazed, nor stored, nor burned), CCP used for litter, and CCP used for other domestic uses (natron, potash, palisades) are not losses at farm level. We did not estimate them in our study, because it was not possible to do so with a survey. However, they represent low level of biomass. CCP grazed by third-party herds or burnt are CCP flows not recovered at farm level. It was not possible to estimate them with our survey. These two flows represent high level of biomass. In our calculations we grouped all these CCP's flows into scarcely (mulch, litter, domestic) or not recovered (grazed by third-party herds, burnt) CCP at farm level.

The definitions and calculation principles of the eight variables selected to characterize CCP and LCP recycling are presented below.

Variable 1: Available crop co-products (*Available CCP*). The *Available CCP* (in kg DM) refers to the total amount of CCP produced after harvest and acquired by the farm during the reference year.

To calculate the *Available CCP*, we quantified:

– the *Available CCP* produced on the farm by converting each plot's grain production as reported by the farmer into a quantity of CCP (in kg DM) using grain/CCP (straw/tops/stalks) conversion ratios coming from bibliographic sources (Autfray et al., 2012; UICN, 2015) completed by personal data (conversion ratios available in Vall & Zoungrana, 2023).

– CCP acquisitions by multiplying the number of trips by the carrying capacity ratio of the means of transport (in kg DM) used by the farmer for each CCP (carrying capacities available in Vall & Zoungrana, 2023).

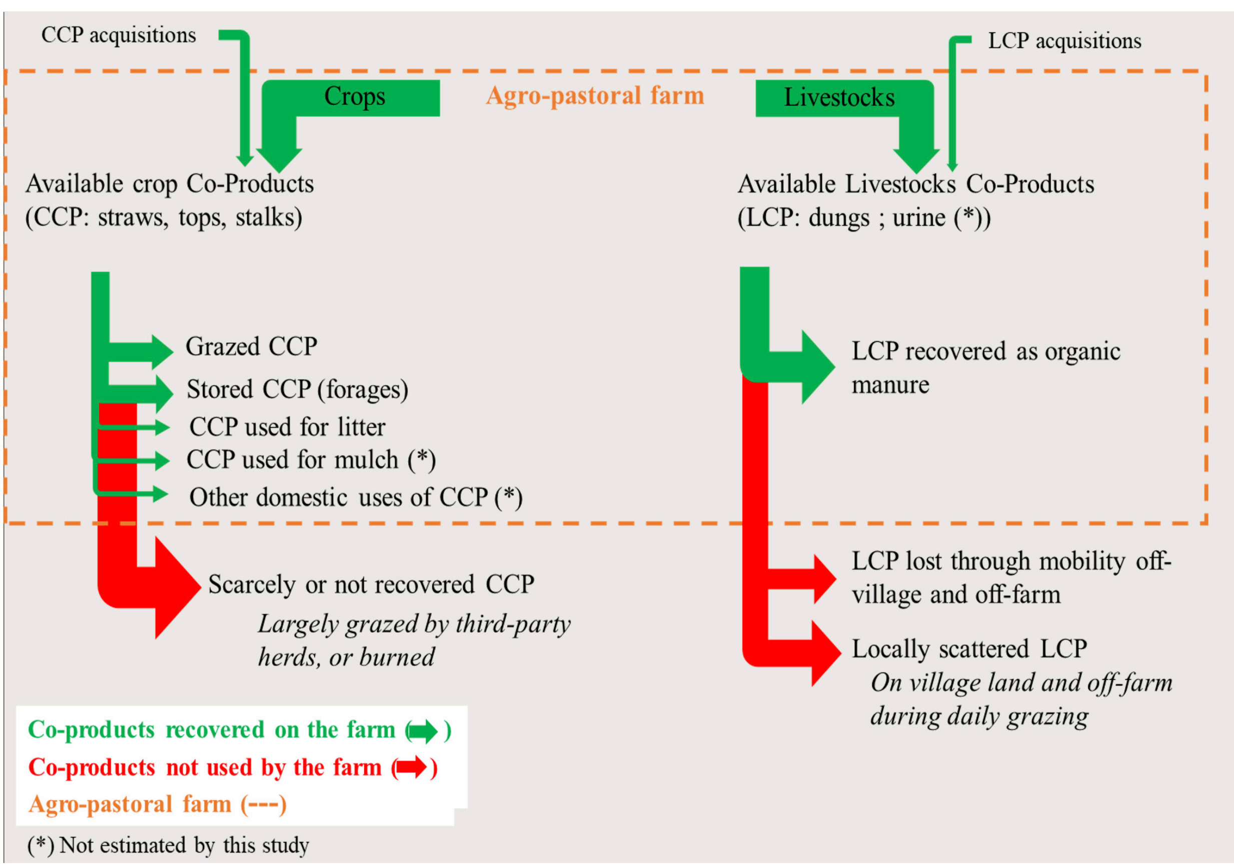

Figure 2. Crop Co-Products (CCP) and Livestock Co-Products (LCP) recovery flowchart at agro-pastoral farm level — *Diagramme de flux de valorisation des Co-Produits Végétaux (CPV) et des Co-Produits Animaux (CPA) à l'échelle de l'exploitation agro-pastorale.*

The sum of all available CCP produced on the farm or obtained through acquisition gave the *Available CCP*.

Variable 2: Crops co-products grazed on cultivated fields (*Grazed CCP*). The *Grazed CCP* (in kg DM) refers to the share of *Available CCP* grazed by the farm's animals on the farm's cultivated plots.

To estimate the amount of CCP grazed on farm plots, we proceeded by animal production units (*Bos Taurus indicus*: draught cattle, fat cattle, suckler cattle; sheep [*Ovis aries*] and goats [*Capra aegagrus hircus*]); considering the number of animals in each unit converted in Tropical Livestock Units; 1 TLU = 1 animal weighing 250 kg; ratios for each animal category available in Vall & Zoungrana, 2023), by plot (considering all cultivated crop plots of the farm that can be grazed by the animals), by season (cool dry season from October to January, and hot dry season from March to May) and given the farmer declaration (number of grazing days [d] and daily grazing time spent on the plot [h]). Thus, for a given unit of animal production (in TLU), a given plot, and a given season, the elementary CCP grazed in kg DM was calculated as follows:

Number of TLU·animal production unit^{-1} x number of grazing days (d) x daily grazing duration on the plot (h) / 10 h (*) x 6.25 kg DM (**)

with *, duration retained for a full day of grazing; **, kg DM ingested per TLU and per day (Guérin et al., 1985).

The sum of all elementary grazed CCP gave the *Grazed CCP*.

Variable 3: Crop co-products stored (*Stored CCP*). The *Stored CCP* (in kg DM) refers to the share of *Available CCP* stored as forage reserve for livestock by the farmers. The stored CCP can be used as a fodder reserve, as litter or for domestic purposes (palisade, potash, natron, etc.).

To quantify the elementary stored CCP, we counted, for each type of CCP (straws, tops, stalks), the number of trips made between the fields, or acquisition sites, and the storage locations (sheds, hay barns, etc.), considering the type of transport used (and their CCP carrying capacity in kg DM; carrying capacities available in Vall & Zoungrana, 2023). For a given CCP and a given means of transport, the number of journeys multiplied by the carrying capacity of the means of transport used for that CCP gave an elementary stored CCP.

The sum of all elementary stored CCP gave the *Stored CCP*.

Variable 4: Scarcely or not recovered crop co-products (*Scarcely or not recovered CCP*). *Scarcely or not recovered CCP* (in kg DM) refer to the share of *Available CCP* that is neither grazed nor stored at farm level. The surveys did not enable us to quantify either CCP grazed by third-party herds, CCP burned (for domestic use [firewood, potash production] or to clear the land) or, by inference, residual CCP recovered for use as mulch following these events. Where communal grazing is open, it is difficult to retain volumes of crop residues in the fields (Giller et al., 2009; Valbuena et al., 2012; Homann-Kee Tui et al., 2015). Hence our reference here to CCP scarcely or not recovered by farms.

The calculating formula for *Scarcely or not recovered CCP* at farm level was as follows:

Available CCP – Stored CCP – Grazed CCP.

Variable 5: Available livestock co-products (*Available LCP*). The *Available LCP* (in kg DM) refers to the total amount of LCP produced during a year by all livestock production units on the farm.

In order to determine the *Available LCP*, we converted the number of animals in each livestock production unit (draught cattle, fattened cattle, suckler cattle, sheep and goats) into TLU. Based on known LCP (dung) production per TLU per year (1,000 kg DM·TLU^{-1}·year^{-1}; Landais & Guérin, 1992), we estimated the *Available LCP* for each livestock production unit using the following formula: Number of TLU·livestock production unit^{-1} x 1,000 kg DM·TLU^{-1}·year^{-1}.

The sum of all available LCP per livestock production unit gave us the *Available LCP*.

Variable 6: Livestock co-products recovered for use as manure (*LCP Recovered as manure*). The *Available LCP Recovered as manure* (in kg DM) refers to the amount of LCP recovered to produce manure. In the daytime, these are LCP deposited by herds on the farm's fields while grazing, or in stalls (pens, paddocks, barns and shelters) by animals kept indoors. At night, these LCP are deposited in stalls, livestock pens and on the fields (in case of overnight field grazing).

The elementary *LCP recovered as manure* were estimated per livestock production unit (draught cattle, fattened cattle, suckler cattle, sheep and goats), and for each season of the year (rainy season, cool dry season and hot dry season), taking into account for each of these situations: the LCP recovered in the various lairage facilities such as enclosures, cattle pens and fodder sheds (at a rate of 1,000 kg DM·year^{-1}/365 days/2 for a 12-hour night, *i.e.* 1.4 kg DM·TLU^{-1}·night^{-1}: see formula 1), and the LCP deposited on the farm's fields by the farm's grazing animals (at a rate of 0.1142 kg

$DM{\cdot}TLU^{-1}{\cdot}h^{-1}$ (1,000 kg $DM{\cdot}year^{-1}$/365 days/24 hours): see formula 2).

Formula (1), for a given lairage facility:

Number of TLU·production $unit^{-1}$ x number of nights (d) x 1.4 kg $DM{\cdot}TLU^{-1}{\cdot}night^{-1}$

Formula (2), for a given plot:

Number of TLU·production $unit^{-1}$ x number of grazing days (d) x grazing time in hours (h) x 0.1142 kg $DM{\cdot}TLU^{-1}{\cdot}h^{-1}$.

The sum of all elementary LCP recovered as manure gave the *LCP Recovered as manure*.

Variable 7: Livestock co-products lost to the farm through livestock mobility (*LCP Lost through mobility*). *LCP Lost through mobility* (in kg DM) refer to the share of *Available LCP* scattered off-farm by animals during periods of mobility. In this study, we considered animals to be mobile when they were geographically away from the village without being able to return at night or during the day to village grounds or close to the farm.

For each livestock production unit, and on the basis that one TLU produces 2.7 kg $DM{\cdot}day^{-1}$ of LCP (1,000 kg $DM{\cdot}year^{-1}$/TLU/365), we calculated the elementary LCP lost through mobility using the following formula:

Number of TLU·livestock production $unit^{-1}$ x number of mobility days (d) x 2.7 kg $DM{\cdot}TLU^{-1}{\cdot}d^{-1}$

The sum of all elementary LCP lost through mobility gave the *LCP Lost Through Mobility*.

Variable 8: Livestock co-products scattered across village land and off-farm (*Locally scattered LCP*). *Locally scattered LCP* (in kg DM) refer to the LCP remaining after deduction of the *LCP Recovered as manure* and the *LCP Lost through mobility*. These are actually LCP scattered across village land (communal land) and off-farm during daytime or night-time grazing hours.

Locally scattered LCP were determined by calculating the difference between: *Available LCP – LCP Recovered as manure – LCP Lost through mobility*.

Estimation of the farm's forages and manure coverage by the recovered co-products. The farm forage needs during the dry season (210 days from November to May) was calculated by livestock production units, considering the number of TLU per unit, and considering that a TLU ingest 6.25kg $DM{\cdot}d^{-1}$ (Guérin et al., 1985). Then we added the needs of all livestock units to estimate the farm forage need. Finally, we compared the farm forage need to the value of the *Stored and Grazed CCP* to estimate the coverage of this need by co-products.

The farm manure need was calculated, considering that the minimum quantity of kg DM of manure per ha needed by a plot of land in Sub-Saharan Savannah is 2.5 t $DM{\cdot}ha^{-1}{\cdot}yr^{-1}$, classically reported in scientific literature (Berger, 1996; Blanchard et al., 2014). The on-farm manure production (in kg DM) was estimated with the following assumptions:

- 10% of the *Stored CCP* distributed as forages were refused by animals and then mix with recovered LCP;
- 50% of CCP and LCP disappear during the manure maturation.

Finally, we compared the farm manure need to the value of the co-products recovered into manure to estimate the coverage of this need by co-products.

2.4. Dataset and data analysis

The parameters, the data and the statistical analysis performed to produce this manuscript were compiled in a Dataset deposited in Dataverse, under the following identifier: doi:10.18167/DVN1/JGEI47.

We analyzed the overall management of CCP and LCP (production, acquisitions and recovery methods in kg DM and in % of *Available CCP and LCP*) on all 60 farms surveyed:

- first on all CCP and LCP;
- then on groups of CCP (cereal straws, maize [*Zea mays*], sorghum [*Sorghum bicolor*], millet [*Pennisetum glaucum*], rice [*Oriza sativa*]), legume tops, groundnut [*Arachis hypogaea*], cowpea [*Vigna unguiculata*], soya [*Glycine max*], Bambara groundnut [*Vigna subterranean*], etc., stalks, mainly cotton and sesam [*Sesamum indicum*]);
- finally on groups of LCP (LCP from draught cattle and fattened cattle, LCP from suckler cattle [main herd], LCP from small ruminants [sheep and goats]).

In order to characterize the diversity of CCP and LCP management systems, we carried out a Principal Component Analysis (PCA) of the data collected from the 60 surveyed farms and the eight variables of CCP and LCP production and recovery (*Available CCP*, *Grazed CCP*, *Stored CCP*, *Scarcely or not recovered CCP*, *Available LCP*, *LCP recovered as manure*, *LCP lost through mobility*, *LCP scattered* around the village; all in kg DM). We then performed a Hierarchical Ascending Classification (HAC) on the five first factorial factors of all 60 individuals. Each

CCP and LCP management system was characterized by two sets of variables:
– 8 PCA variables (see list above);
– 16 farm structure variables (workforce, cultivated area, livestock numbers, CCP and LCP management equipment).

Lastly, we conducted an Analysis of Variance (ANOVA) and a Newman-Keuls test on all 24 variables in order to test the significance of the observed differences at the 5% threshold.

3. RESULTS

3.1. Annual CCP and LCP management at farm level

Table 1 gives an overview of the outcomes of the *Available CCP and LCP* on the 60 farms surveyed.

The *Available CCP* per farm amounts to approximatively 21 tons DM, with 12% *Grazed*, 11% *Stored as forage*, and 77% *Scarcely or not recovered by the farm*. According to the farmers declarations, a significant proportion of the *Scarcely or not recovered CCP* is grazed by outside herds or burnt, and a marginal proportion is recovered as mulch. These statements are consistent with our observations. The *Available LCP* per farm amounts to approximatively 24 tons of DM, with 40% *Recovered as organic matter*, 25% *Lost through mobility*, and 35% *Locally scattered*. LCPs are scattered locally when herds graze village lands that does not belong to the farm. Adding this to the LCP *Lost through mobility* gives a total of 60% of LCP not recycled by the farm.

Table 1 shows the outcome of CCP grouped into three categories: cereal straws, legume tops and stalks (cotton and sesame). The vast majority of CCPs are stored for fodder purposes (99,77%) and 0,23% for bedding purposes (only sesame stems).

The *Available cereal straw CCP* amounts to approximatively 14 tons DM, with 15% *Grazed* and 14% *Stored as forage*. A considerable portion of the *Available Straw CCP* (71%) is *Scarcely or not recovered by the farm* (our observations suggest that bulk of is grazed by third party herds, a small part is burnt, and a small part is left on the ground as mulch).

The *Available Legume Top CCP* amounts to approximatively 1.6 tons DM, with 12% *Grazed* and 26% *Stored as forage*. More than half of the *Available Legume Tops CCP* (62%) is *Scarcely or not recovered by the farm* because a large part of the tops harvested at the end of the rainy season rot on site.

The *Available CCP* from the stalks (mostly cotton) amounts to approximatively 6 tons DM, with 5% *Grazed* (only cotton leaves) and a negligible quantity Stored as bedding (only 2% of available sesam stalks in two farms representing less than 200 kg DM). Nearly all of the *Available CCP stalks* (94%) is burnt and not recycled by the farms. When farmers burn CCP, they loss biomass and N, but ashes return to the soil (P and K).

LCP were grouped into three categories, based on each livestock production unit's operating mode (**Table 1**):
– draft and fattened cattle LCP (animals mainly kept indoors);
– suckler cattle LCP (herds grazed and often moved);
– small ruminant LCP (sheep and goats).

The *Available Draught and Fattened Cattle LCP* amounts to approximatively 5 tons DM, with 48% *Recovered as manure* and 10% *Lost through mobility*. A significant proportion of the *Available Draught and Fattened Cattle LCP* (42%) is *Scattered locally* during daily pastures.

The *Available Suckler Cattle LCP* amounts to approximatively 14 tons DM, with 35% *Recovered as manure*, 34% *Lost through mobility*, and 31% is *Scattered locally* during daily off-farm grazing around the village. These animals, which are often moved around, display very high rates of LCP *Lost through mobility*.

The *Available Small Ruminants LCP* amounts to approximatively 5 tons DM, with 44% *Recovered as manure* and 15% *Lost through mobility*. A significant proportion of the *Available Small Ruminants LCP* (41%) is *Scattered locally* during daily pastures.

3.2. Typology of CCP and LCP management systems

Data analysis revealed 4 CCP and LCP management systems (groups G1, G2, G3 and G4: **Table 2**). The structural characteristics of the farms in the four groups are presented in **table 3**. These four systems are described below in relation to CCP and LCP management practices and the structural characteristics of the farms in each group.

The G1 Group (23% of the sample) is made up the smallest crop-oriented farms (8.6 ha), 17 TLU, fairly well equipped with transport and forage storage equipment (~5 units). These farms have the lowest level of *Available CCP* (~12 tons). They boast the highest level of *Stored CCP* for forages purposes (28% of the *Available CCP*), as well as a high percentage of *Grazed CCP* (21%), as CCP represents an important unpaid household resource for these smallholders. Their level of *CCP Recover as manure* stands at 49%, which is the highest in our sample. Their level of *LCP recovered as manure* is 50%. *LCP Lost through mobility* are limited (4%), as mobility is not required due to small herd size.

Table 1. Crop Co-Product (CCP) and Livestock Co-Products (LCP) management over the course of a year (in kg DM and % of Available CCP and LCP): at farm level, at farm crops production units (cereals straw, pulses tops, cotton/sesame stalks), at farm livestock units (draught and fattened cattle; suckler cattle; sheeps and goats) — *Gestion des Co-Produits Végétaux (CPV) et des Co-Produits Animaux (CPA) sur une année (en kg MS et % de CPV et CPA Disponibles) : au niveau de l'exploitation, des unités de production de cultures (paille de céréales, légumineuses, tiges de coton/sésame), des unités d'élevage (bovins de trait et d'engraissement ; bovins allaitants ; ovins et caprins).*

Co-products	**Variable**	**Average** (kg DM)	**Standard deviation** (kg DM)	**Availability** (%)
Farm level				
CCP	Available CCP	21,121	16,859	100
	Grazed CCP	2,627	2,990	12
	Stored CCP	2,336	2,253	11
	Scarcely or not recovered CCP	16,158	13,956	77
LCP	Available LCP	24,046	21,386	100
	LCP recovered as manure	9,539	9,083	40
	LCP lost through mobility	5,936	12,730	25
	LCP scattered around the village	8,571	8,785	35
Crops production units				
Cereal straws	Available CCP	13,717	10,648	100
	Grazed CCP	2,118	2,511	15
	Stored CCP	1,908	2,036	14
	Scarcely or not recovered CCP	9,691	8,933	71
Legume tops	Available CCP	1,609	1,672	100
	Grazed CCP	191	320	12
	Stored CCP	423	474	26
	Scarcely or not recovered CCP	995	1,329	62
Cotton and sesame stalks	Available CCP	5,795	7,373	100
	Grazed CCP	318	589	5
	Stored CCP	5	29	0
	Scarcely or not recovered CCP	5,471	6,863	95
Farm livestock production units				
Draught and fattened cattle	Available LCP	4,998	4,594	100
	LCP recovered as manure	2,410	2,391	48
	LCP lost through mobility	467	1,315	10
	Locally scattered LCP	2,121	2,212	42
Suckler cattle	Available LCP	13,925	17,025	100
	LCP recovered as manure	4,857	6,919	35
	LCP lost through mobility	4,686	9,906	34
	Locally scattered LCP	4,382	6,640	31
Sheeps and goats	Available LCP	5,124	4,000	100
	LCP recovered as manure	2,272	1,951	44
	LCP lost through mobility	784	1,950	15
	Locally scattered LCP	2,068	1,855	41

Table 2. Typology of Crop Co-Products (CCP) and Livestock Co-Products (LCP) management systems — *Typologie des systèmes de gestion des Co-Produits Végétaux (CPV) et des Co-Produits Animaux (CPA).*

CCP and LCP management systems		**G1**	**G2**	**G3**	**G4**	**Pr > F (Modèle)**
Farms involved	Number	14	29	5	12	
	%	23	48	9	20	
Crop Co-Products (CCP)						
Available CCP	kg DM	12,301^{b}	20 190^{b}	46,796^{a}	22,964^{b}	0.001
Grazed CCP	%	21^{a}	9^{b}	16^{ab}	11^{b}	0.002
Stored CCP	%	28^{a}	9^{b}	15^{b}	8^{b}	< 0.0001
Scarcely or not recovered CCP	%	51^{c}	81^{a}	69^{b}	81^{a}	< 0.0001
Livestock Co-Products (LCP)						
Available LCP	kg DM	17,586^{c}	14 121^{c}	59,991^{a}	40,590^{b}	< 0.0001
LCP recovered as manure	%	50^{a}	53^{a}	50^{a}	19^{b}	< 0.0001
LCP lost through mobility	%	4^{b}	1^{b}	6^{b}	66^{a}	< 0.0001
Locally scattered LCP	%	45^{a}	46^{a}	44^{a}	15^{b}	< 0.0001

$^{a, b, c}$: on the same line, values with different letters are statistically different, $p < 0.05$ — *sur la même ligne, les valeurs avec des lettres différentes sont statistiquement différentes,* p < *0,05.*

Table 3. Farms' structural characteristics in relation to Crops Co-Products (CCP) and Livestock Co-Products (LCP) management systems — *Caractéristiques structurelles des exploitations en fonction des systèmes de gestion des Co-Produits Végétaux (CPV) et des Co-Produits Animaux (CPA).*

Group	**Unit**	**G1**	**G2**	**G3**	**G4**	**Average**	**Pr > F(Modèle)**
Number of adults	U	5.1	7.8	9.2	7.8	7.3	0.193
Cultivated area	Ha	8.6	11.9	19.5	14.0	12.2	0.141
Cotton_Sesam	%	22	34	29	28	29	0.297
Cereals	%	61	47	53	64	54	0.088
Legumes	%	17	19	18	8	16	0.182
Farm Livestock	TLU	17^{c}	14^{c}	59^{a}	40^{b}	23.5	< 0.0001
Farm Draught cattle	%	29^{ab}	44^{a}	14^{b}	14^{b}	32	0.001
Farm Fattened cattle	%	0b	0b	7^{a}	0b	1	0.012
Farm Suckler cattle	%	43^{ab}	24^{b}	59^{a}	66^{a}	40	< 0.0001
Farm Sheep	%	15	13	10	11	13	0.729
Farm Goats	%	13	19	9	9	15	0.257
Transport equipment	U	1.4	1.3	2.4	1.4	1.5	0.212
Livestock pens	U	0.6^{b}	0.5^{b}	1.6^{a}	1.0^{ab}	0.7	0.014
Stalls	U	0.6	0.6	1.2	0.2	0.6	0.098
Sheds	U	1.6	1.3	2.0	1.3	1.5	0.244
Manure pits	U	0.5	0.7	1.0	0.3	0.6	0.182
Total of equipements	U	4.8	4.4	8.2	4.3	4.8	

1 TLU = one head of cattle weighing 250 kg — *une tête de bétail pesant 250 kg* ; $^{a, b, c}$: on the same line, values with different letters are statistically different, $p < 0.05$ — *sur une même ligne, les valeurs avec des lettres différentes sont statistiquement différentes,* p < *0,05.*

However, grazing on village land leads to a high level *Locally scattered LCP* (45%).

The G2 Group (48% of the sample) is made up larger crop-oriented farms than G1, with larger cultivated areas (11.9 ha) and smaller livestock numbers (14 TLU). The number of transport facilities and CCP/LCP management infrastructure are lower than in G1 (~4 units). Compared to G1, *Available CCP* is higher (~20 tons) and *Available LCP* is lower (~14 tons), which is consistent with the extent of cropland and livestock on farms. This group boasts the second lowest level of *Stored CCP* (9% of the *Available CCP*), just ahead of G4. The low level of *Grazed CCP* (9%) is due to the fact that farms have a fairly high level of *Available CCP* relative to the feed requirements of their small herds. This group has the lowest recycling rate of CCP (19%), which may be related to a limited herd and lower forage requirements. The level of *LCP Recovered as manure* stands at 53%. *LCP Lost through mobility* is almost nil (1%), as mandatory periodic mobility is not required due to modest herd size. However, grazing on village lands leads to significant level of *Locally scattered LCP* (46%).

The G3 Group, which accounts for 9% of the sample, is made up of very large crops-livestock-oriented farms (19.5 ha, 59 TLU) boasting the best facilities in terms of transport equipment and CCP/LCP management infrastructure (8 units). These farms have the highest level of *Available CCP* and *LCP* (~47 tons and ~60 tons). In this group, the levels of *CCP Storage* and *CCP Grazing* are quite high (respectively 15% and 16% of the *Available CCP*), which is understandable given the large size of the herds. The CCP recycling rate is equally significant in this group (31%). G3 levels of *LCP Recovered as manure* stand at 50% (almost equivalent to G1 and G2). Despite the large size of the herds, the percentage of *LCP Lost through mobility* is low (6%) because these farmers choose to keep their livestock in the village all year round. However, grazing on village land leads to a significant level of *Locally scattered LCP* (44%; level almost equivalent to G1 and G2).

The G4 Group, which accounts for 20% of the sample, is made up of crops-livestock-oriented farms with important livestock numbers (40 TLU), and large cultivated areas (14 ha), and lower standards of transport equipment and CCP/LCP management infrastructure (~4 units). These farms exhibit an average level of *Available CCP* (~23 tons) and a high level of *Available LCP* (~41 tons), commensurate with the size of their herds. These farms with large herds favor CCP grazing (11% of *Available CCP*), with little CCP storage (8% of *Available CCP* - similar to G2), since animals in this group are often moved around. This active approach to mobility has a strong negative impact on LCP recycling (66% of *Available LCP* lost through mobility). Only 19% of LCP are indeed recovered for use as manure on G4 farms. In this group, the extended periods of livestock mobility and absence from the farms also account for the farmers' lack of interest in CCP storage.

According to our calculation assumptions as shown in **table 4**, CCP and LCP recycled as forage and manure only partially meets farm needs: 16% for forage; 16% for manure. However, if we consider the CCP recycling:

- in the G1 Group, which boasts the highest *CCP storage* rate (28%), 25% of forage needs are met;
- at the opposite in the G4 group, strong livestock mobility between December and February (after on-farm fields CCP grazing period) and June (when the grass started to grow back after the first rains) and the low level of forage storage accounts for the low coverage of forage requirements (8%) despite high levels of *Available CCP*;
- G2 and G3 are in intermediate situations. If we consider the LCP recycling: G1 and G3 group, which are best equipped with transport equipment and manure production infrastructures (see **table 3**), have the best coverage rates for manure needs.

4. DISCUSSION

4.1. Low but rising levels of CCP and LCP recycling

Many studies on co-product recycling in the savannah areas of Sub-Saharan Africa show that co-products are poorly recovered at the farm level. In Western Burkina Faso, our finding shows that at farm level the rate of CCP and LCP recycling is very low, with only 23% of CCP recovered as forage, 40% of LCP recovered as organic fertilizer and a small proportion of CCP recovered as mulch (mulch amount not assessed in this study). For the same area Andrieu et al. (2015), Bénégabou et al. (2017) and Berre et al. (2021) reported the same trends. Andrieu et al. (2015) reported that 80% of crops co-products are abandoned in the fields. Benagabou et al. (2017) reported a poor coverage of farm forages needs with CCP. Berre et al. (2021) reported a poor coverage of farm manure needs with co-products.

Research conducted in Southern Mali and Northern Cameroon, where farming systems are comparable to those in Western Burkina Faso (cotton, cereals, livestock) report the same or different trends.

In Southern Mali, Blanchard et al. (2013) found that farmers recycle 41% of CCP and 44% of LCP. This high level of CCP and LCP recycling may be explained by a strong emphasis on crop-livestock integration by development bodies since the 1990s and

Table 4. Coverage assessment of farm needs for forage and manure through CCP and LCP recycling — *Évaluation de la couverture des besoins des exploitations en fourrage et en fumure organique par le recyclage de CPV et CPA*.

Group	G1	G2	G3	G4	Average
Farm needs for forage during the dry season (kg DM)	22,584	18,135	77,044	52,128	30,881
Grazed and stored CCP during the dry season (kg DM)	5,651	3,563	12,688	4,324	4,963
CCP coverage of farm needs for forage (%)	25	20	16	8	16
Farm needs for manure (kg DM)	21,616	29,720	48,675	34,896	30,444
CCP and LCP recovered as manure (kg DM)	4,554	3,695	15,183	3,862	4,886
CCP and LCP coverage of farm needs for manure (%)	21	12	31	11	16

by the farms' good standards of transport equipment and CCP/LCP management infrastructure (forage sheds, farm and field pits, livestock pens with bedding supply) (Falconnier et al., 2015). However, co-product recovery level depends on the areas, as shown by Traoré et al. (2022) study which highlights a poor crops co-products recycling.

In Northern Cameroon, Dugué (1999) and Dongmo et al. (2012b) showed that only about 10% of CCP were recycled and that the percentage of LCP scattered off-farm was very high. In Northern Cameroon, low levels of CCP and LCP recycling can be attributed to two factors: very low standards of transport equipment and CCP/LCP management infrastructure on the farms (Vall et al., 2017) and high herd mobility and high grazing pressure (Dongmo et al., 2012a). Therefore, compared to Northern Cameroon (very low recycling rates) and Southern Mali (good recycling rates), CCP and LCP recycling rates in Western Burkina Faso are average.

However, CCP and LCP recovery as forage and manure only partially meets farm needs, despite ample reserves. There is therefore considerable scope for improving recycling rates at this level.

4.2. CCP and LCP recycling efficiency drivers

For farms, the management of livestock mobility and common land grazing leads to significant losses and scattering of CCP and LCP. The study shows that across all farms, 25% of the *Available LCP* is lost when animals are on the move, with losses reaching 64% of the *Available LCP* on farms that engage in active mobility (G4). Similarly, the practice of common land grazing (open access to fields for post-harvest CCP grazing) is frequently a major source of CCP loss for farms. This is the case when herds from outside the farm, with many heads, enter to graze on the farm's harvested fields. Third-party herds from the neighbourhood or from passing transhumant herders actually graze a very large proportion of the 77% of CCP that are *Scarcely or not recovered* by the farms. Our survey data did not allow us to assess the amount of CCP grazed by third-party herds on common land. In Southern Mali, Autfray et al. (2012) estimated common land CCP grazing at 38%. Semporé (2008) showed that in our study area, about 15% of maize straw biomass remained on the ground at the end of the dry season, which provides an indication as to the proportion of CCP grazed by third party herds (around 60% of the *Available CCP*). In short, one of the main causes of low CCP and LCP recycling lies at local level. But how can livestock daily mobility and common land grazing be better regulated locally so as to improve CCP and LCP recycling both at village and farm levels? This would require changes in rules and legislation. With ever-increasing pressure (Dongmo et al., 2012c) on land and resources, action is urgently needed, but this is easier said than done. There have been numerous attempts to develop rules for access to agro-sylvo-pastoral resources recognized by the populations and by the authorities, but these local charters and conventions are often difficult to apply (Vall et al., 2015). And for these reasons, we also recommend improving the management of co-products at the farm level.

CCP are recycled according to their forage value. On average, 12% of the *Available CCP* is grazed and 11% is stored for forage purposes. However, these figures vary greatly depending on CCP type. Legume top CCP, which boast the highest forage value (crude protein: 170-180 g·kg^{-1} DM [INRA, 2018]), are primarily stored for forage purposes (26% of the *Available CCP*). Straw CCP, whose forage value is much lower (crude protein: 70-90 g·kg^{-1} DM [INRA, 2018]), are stored and grazed in similar proportions (14% and 15% respectively). Lastly, cotton stalks (which have no forage value) are virtually not recycled at all. In Southern Mali, Autfray et al. (2012) revealed a 68% recycle rate for Straw CCP (19% as forage stocks and 49% for grazing), compared to only 14% forage recycle rate for Stalk CCP (*vs* 5% in Burkina Faso), with Stalk CCP being mostly recycled as bedding (20% of the *Available CCP*). In Western Burkina Faso, nearly all cotton stalks are burned in order to disrupt pest breeding cycles on this crop. Farmers are not yet sufficiently aware of the possibility of using cotton stalks for bedding and compost, as is widely done by farmers in Southern Mali (Autfray et al., 2012; Blanchard et al., 2013; Blanchard et al., 2014).

Equipment and infrastructure levels, and the continued presence of livestock on the farm have a positive effect on CCP and LCP recovery rates. For G3 farmers, equipment availability, as well as the continued presence of livestock, both account for achieve higher levels of CCP and LCP recovery. By contrast, in the G1, G2 and G4 groups, where standards of transport equipment and CCP/LCP recycling infrastructure are lower, and presence of livestock on farm is more limited particularly in G4 where animals are away for a large part of the year, CCP/LCP recovery is poorer than in G3. As reported in the study of Semporé et al. (2016) in the same area, farmers are well aware of the benefits of these factors on co-products recycling.

4.3. Limit of the study and proposal to improve farm-level CCP and LCP recycling

Co-products flows not included in the study. Our method did not make it possible to estimate the following co-product flows, which should be considered to make a more consistent and precise evaluation of these flows at farm level.

CCPs grazed and LCP deposits by third parties' herds on farm plots: in an open agrarian system where open grazing is practiced and where the harvested cultivated plots escape the supervision of farmers due to their distance and dispersion, it is highly challenging to estimate with a single-pass survey the CCP grazed by external herds and LCP deposits on farm plots. To do this, it would be necessary to set up weekly monitoring of the plots throughout the dry season, as proposed by Mikicic et al. (2023).

It is not easy to estimate the vegetal cover of the soil (by CCP) with a survey. To do this, it would be necessary to have a visual scoring grid of vegetal soil cover (by CCP) for all crops allowing the surveyed farmer to indicate the level of cover on each plot. No such grid exists. Thiébeau & Recous (2016) proposed a method based on the use of sampling plots located along a transect which is precise to assess the vegetal cover but time-consuming.

Although root biomass is considered to be a CCP, it could not be estimated. It could be included in the assessment of CCP flows at the farm level. All of this biomass located in the soils of the farm's plots benefits the latter.

Due to the daytime mobility of herds, and due to the absence of cemented night-time rest areas, urine collection is very complicated. But it must be admitted that a fraction of night-time urine mixes with solid LCP.

Proposal to improve farm-level CCP and LCP recycling. Given the low rate of coverage of farm needs for forages and manure (16%) and the significant reserves of CCP and LCP that could be recycled on farms (respectively up to 77% and 60%), we are testing and developing a digital tool to assess and advice a farmer for improving the management of CCP and LCP at his farm level:

The assessment consists of establishing a baseline situation on the current management of CCP and LCP at farm level, considering all farm crops and livestock units, in order to determine the proportion of CCPs and PCAs not recovered.

The advice aims to research and establish with the farmer a strategy for a smart recycling of CCP and LCP for the coming year, considering the reference situation and the productions of CCPs and LCPs to come. And here are some examples of levers at farm level that we are going to promote through the digital tool: harvest of straws and legume tops before common grazing start; extend the grazing periods of CCPs after harvest; extend the on-plots herd night park period for farm with large number of cattle; increase use of cotton stalks for litter in pens, in order to produce manure; and implement CCP's protection measures on the farm's plots to increase the plant cover of the soil.

This proposal at the farm level is not sufficient to improve the overall management of CCP and LCP. It is also essential to consider the recycling of co-products at the scale of territories and ecosystems to meet the needs of all human and non-human users of these co-products. At this scale, the challenge mainly consists of developing socially accepted rules of use and access to co-products and the spaces where they are produced (Tittonell et al., 2015; Vall et al., 2015; Bosma et al., 1999).

5. CONCLUSIONS

In agro-pastoral farms in western Burkina Faso, 77% of *Available CCP* and 60% of *Available LCP* are not recycled for the farms' own needs, and CCP/LCP recycled only covers 16% of the farms' forage needs and 16% of their manure needs. Forage value of CCP, livestock mobility, available manpower, level of transport equipment, level of CCP/LCP management equipment, are factors that affect strongly the level of co-products recycling at the farm level.

This study provided data on the recycling of CCP and LCP on agro-pastoral farms. However, the survey method did not allow us to assess all forms of farm-recycling of CCP and LCP (mulch) or farm-non-recycling of CCP and LCP (grazing by third parties, burned, etc.). Agroecology needs new methods and metrics to be better evaluated and this agroecological engineering remains to be developed and documented.

In order to advice farmers in improving the recycling of CCP and LCP, we are testing and developing an assessment and advisory tool on the management of all these co-products at the farm level.

Lastly, it is important to keep in mind that the improvement of CCP and LCP recycling is not only an issue at the farm level, but in a broader environment, that of the territory.

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