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The Contribution of Mobile Pastoral Herds to Soil Fertility Maintenance in Sedentary Mixed Crop-Livestock Systems at Farm and Territory Scales—Part of Mutually Reinforcing Social and Ecological Relationships Supporting Sustainability

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Agricultural development through settlement schemes on desert lands has always raised acute debates, especially over environmental issues due to cultivation based on intensive additions of water and fertilizers. However, nutrient cycling approaches at the farm level are generally based on apparent N flows, i.e., purchased inputs and sold products, without considering nutrient flows driven by mobile herds crossing the arable lands of sedentary farmers. Through a territory level approach, the present study aimed to assess the contribution of mobile pastoral herds located in the newly reclaimed land on the western desert edge of the Nile Delta on the supply of the manure for local sedentary farms. Based on a survey of 175 farmers, we calculated the partial farm nitrogen balances. Supplemental interviews were conducted with the pastoral community to assess the additional manure coming from grazing practices in the research area. The results show that the sedentary mixed crop-livestock systems based on the planting of *Trifolium alexandrinum* and a manure supply make a useful contribution toward converting poor, marginal soil into fertile soil. Moreover, grazing of crop residue by pastoral herds on the reclaimed land contributes to social sustainability by maintaining social links between the first occupants, the Bedouins, and the new settlers. Grazing accounts for 9% to 34% of farm-level N input and 25% to 64% of farm-level N output depending on the village and the cropping system. This contribution calls for different rural policies that consider the complementarity between pastoral herders and sedentary farmers that supports both systems' social and environmental sustainability.

Keywords: crop-livestock systems, nitrogen balance, manure input, pastoral system, social interactions, reclaimed lands, Egypt

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INTRODUCTION

Recent studies highlight the multiple benefits of integrated crop-livestock production systems in terms of the diversification of farm activities and the creation of a safety net that decreases farm household vulnerability (Barrett et al., 2001; Alary et al., 2011), and also in terms of efficiency and sustainability, partly due to the contribution of livestock to nutrient cycling (Powell et al., 1996; Herrero et al., 2010; Powell and Rotz, 2015). Nutrient balance and use efficiency are widely used as indicators to assess the dynamics of nutrient cycling and soil fertility (Stoorvogel and Smaling, 1990; Tittonell et al., 2005). The plot and the farm (or the household) are usually the reference points for estimating these indicators. However, farm-level approaches generally underestimate the nutrient flows driven by mobile livestock within a territory as pastoral herders traverse a wider area. Moreover, most social and ecological studies on the new cultivated zones in harsh environments shared by mobile herders and sedentary farmers highlight the conflictual and recurrent resource ownership problems and access (Bassett, 1988; Thebaud and Butterbury, 2001; Galvin, 2009). In this context, Powell et al. (1996) illustrated how land use and tenure policies inhibit livestock mobility. These rules reduce the farmer's access to manure from pastoral herds, increasing the need for other external nutrient inputs, such as mineral fertilizers, to prevent a decline in soil fertility and crop yields. This phenomenon is particularly acute in desert reclaimed lands that require significant nutrient additions before being cultivated and productive. Simultaneously, their settlement is largely criticized for displacing indigenous people, including pastoralists, which potentially strains the relationship between the two groups. Few studies integrate manure management's social and environmental dimensions at the territory level [as mentioned by Schlecht et al. (2004) and Vayssières et al. (2017)]. The present study aimed to assess mobile pastoral herds' environmental and social contributions at the territory level by focusing on nutrient flows and the consequent social interactions between pastoral herders and farmers.

The study area was the newly reclaimed arid lands (NRLs) at the West of the Nile Delta in Egypt. Generally, the location of these reclaimed lands, which are on sandy soils and supplied with pressurized irrigation water by sprinklers or drippers, make them suitable for the development of modern agriculture centered on cash crops. However, productivity in the NRLs has consistently remained low compared to the Nile Valley's older lands (Enien et al., 2000). The conversion of new desert soils to economically sustainable systems is a significant challenge in agricultural development. Crop fertilization and soil fertility management have been identified as crucial issues for farm intensification and diversification to realize the full agronomic and economic return of the newly reclaimed desert land (El Nahrawy, 2011). Under arid conditions and on sandy soils, manure increases biological activity in the soil and enhances soil properties. However, large amounts of N can be lost by leaching depending on the cropping system and water management (Cameron et al., 2013). These losses can reach 40–60% in the case of overuse of mineral fertilizers and over-irrigation, threatening social and ecosystem health in Egypt (Monem et al., 1997). In the context of newly reclaimed lands in Egypt, it is essential to improve soil properties without compromising the nitrogen balance. Manure is an important source of N, and it can enhance the physical structure of soils, subsequently improving stability and productivity (Hauck, 1978).

The reclaimed arid lands in the western part of the Nile Delta represent ∼40% of total Egypt's NRL, spawning from a national agricultural policy started in the 1960s to achieve different goals. Among them, we can cite the objectives of food security, rural employment, and increases in the export of crop products via the agriculture sector's modernization (Meyer, 1998). In the 70s, under Al Sadat's presidency, the preference for land attribution was given to agricultural high school or University graduates who were seen as promising individuals for new agricultural development (Mansour and Ismail, 1993). In the 80s, with the Mubarak National Resettlement Scheme for Graduates (MRS), land distribution was extended to all graduates from all types of high school programs and University faculties (Meyer, 1998). From the mid-90s, the National Resettlement Scheme has been extended to many beneficiaries, e.g., early retirees from the public sector, evicted land tenants, or female heads of households. Thus, the newly reclaimed land in Egypt has a variety of beneficiaries, which explains the range of farming systems (Alary et al., 2018) and complexifies these territories' social context.

Our objective was to assess mobile pastoral herds' contribution, which are located in the NRLs, to the supply of manure to local farms. Specifically, the study focused on the N supply from manure used by various crop-livestock systems. At the farm level, the N flow analysis allowed us to estimate the N contribution of livestock to the total N input. Comparing results to N exportation through livestock and crop products, we calculated the N balance. The N input and output are computed from a farm survey in the NRLs of the West Nile Delta. Supplemental interviews were conducted with the pastoral community to assess the additional manure coming from grazing practices in the research area. One of the leading hypotheses tested herein was that grazing livestock activities and herd mobility constitute a pillar of environmental and social sustainability in the Mediterranean rural zone. Moreover, their role is essential at different scales, i.e., both at the farm level (soil fertility and structure, forage supply, and household livelihoods) and at the territory level (relationships between herders and farmers, and N flows).

MATERIALS AND METHODS

Case Study and Materials

In the NRLs, various fertilization practices are embedded in the diversity of new settlers and cropping systems implemented on the newly reclaimed farmland. Thus, five zones in the NRLs were chosen according to a chronological gradient of land reclamation: Nahda in the reclaimed land settled in the 1960s (called Old NRLs), Sukhar el-Bangar (also called Bangar) primarily reclaimed in the 1980s, and Hammam in the 1990s, and Tiba and Bustan extension (New NRLs), settled at the end of the 90s (**Figure 1**) (Alary et al., 2018). Three villages

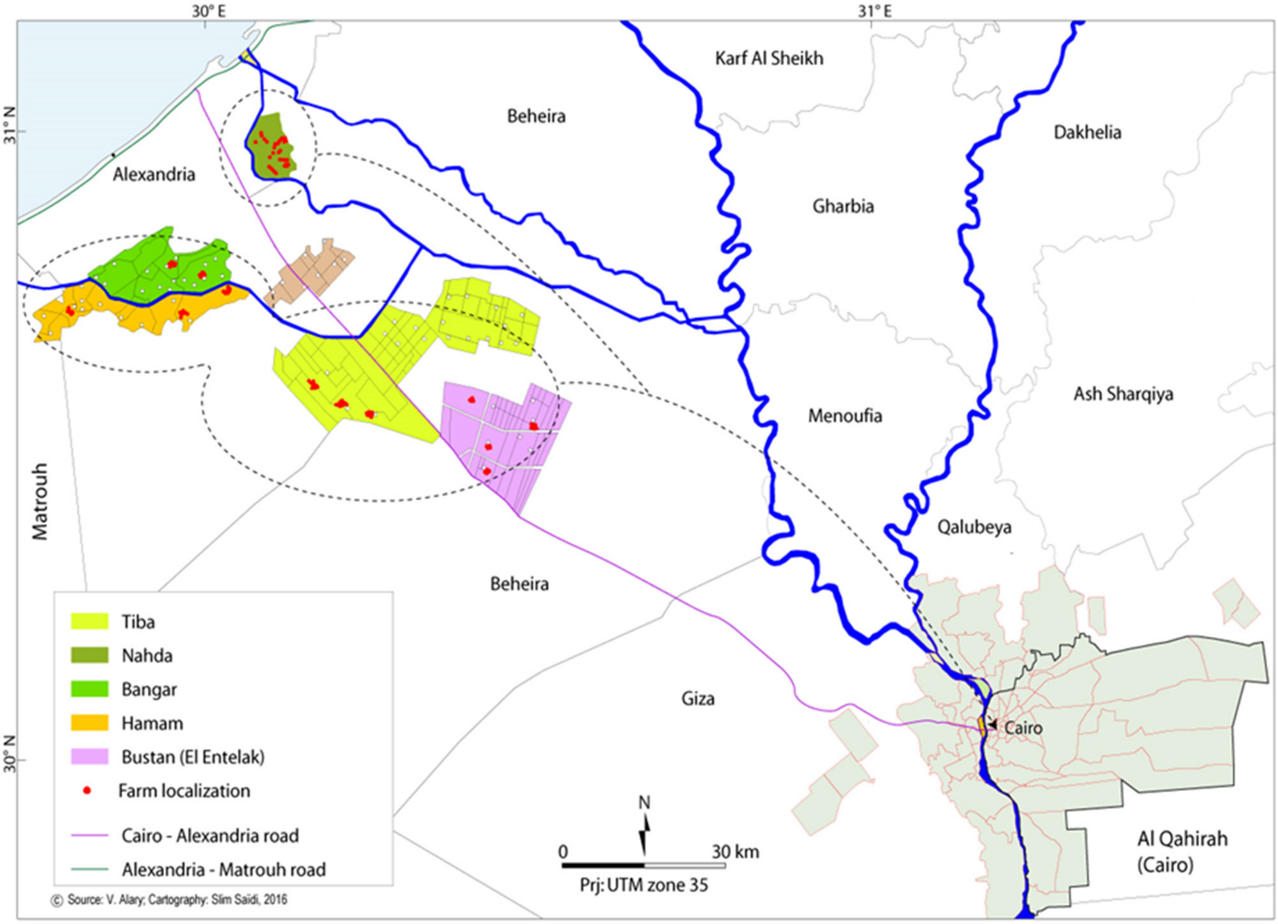

FIGURE 1 | The geographical location of the selected zones in the New reclaimed lands of the western part of Nile Delta (Egypt) (extracted from Alary et al., 2016, http://agritrop.cirad.fr/584660/).

were selected in each zone to reflect the diversity of land beneficiaries in each zone. Using snowball sampling (Goodman, 1961), we identified and surveyed 10 farmers per village. The target population was small and medium farms (from < 1 to < 2 ha). A total of 160 farmers, from small to medium farms, were surveyed in 2013 and 2014. Additionally, 15 farmers representing large farms were interviewed in 2014 to consider the diversity of farming systems. The final sample included 175 farmers (Juanes et al., 2020).

We developed and applied a semi-open-ended questionnaire for use at the farm level (Juanes et al., 2020). We explored three components in the farm survey: (1) family and house descriptions to assess family living conditions, (2) descriptions of the land and cropping systems used, including use of organic and mineral fertilizers, and (3) livestock structure and management, i.e., feeding system, animal movements (entries and exits), and animal performances.

For this paper, we selected the small and medium farms and removed two farms with incomplete datasets for crop management practices. In total, our final sample was 158 farms. Our sample was reduced to 154 farms for the calculation of agronomic indicators due to a lack of data on manuring practices on four farms.

Additionally, we conducted complementary interviews with Bedouin pastoralists around Tiba to understand the herds' contribution to manure provision and N supply for sedentary farms in the area (see **Supplemental Material c**). This fieldwork involved open-ended interviews with 10 Bedouin herders operating in the Tiba area. Each interview was composed of three parts: (1) history of the farmers and their family in the zone, (2) herd composition and the calendar of grazing per month over the previous year, and (3) arrangements and grazing costs. This research revealed the social and environmental links between the settled farms and Bedouin livestock systems by analyzing grazing practices and contracts at a territory level. Consequently, these practices were examined in conjunction with the diversity of farming systems in the Tiba zone.

Diversity of Settled Crop-Livestock Farming Systems

Considering the diversity of farming systems in the NRLs due to the gradient of settlement and the settlers' differential background (Alary et al., 2018), we used a multiple factorial analysis (MFA) to identify and characterize the prevailing farming systems. The variables in the MFA were: (1) the livelihood assets representing "family" characteristics (family structure, education level, family workers), "land" access (land tenure, cultivated land), and "livestock" asset (animal stock, livestock composition per species), and (2) farm management related to "labor" (contribution of family members and occasional workers), the "cropping system" (land use), and "livestock" system (animal management and performance). In these mixed crop-livestock systems, "dairy activity" reflects the degree of intensification regarding livestock activity and its position in the farming system. In total, we chose 37 variables classified into six thematic groups to understand the diversity of structure and functioning of the farm systems (**Table 1**). The variables of land tenure and district were projected as supplemental variables. The MFA approach allow us to calculate a series of scores that expressed similarities and differences between families. These scores were used to construct a hierarchy of partitions through agglomerative hierarchical classification (AHC) (Manly, 1994). All calculations were performed using the ADE4 package (Thioulouse et al., 1997) in R software (R Core Team, 2014) and resulted in clusters that characterize the prevailing farming systems in the entire zone.

TABLE 1 | Active variables classified into six thematic groups to represent the diversity of family farming systems in the newly reclaimed lands (Egypt).

Themes	Variables	Main hypothesis
Family	Education of the family head Age of the family head Family size; % schooled children; Number of children working on the farm; Number of potential male workers in the family; Number of potential female workers in the family; Number of family members working outside the farm; The number of family members who can work out of the farm.	Human asset, especially family composition and educational level, explain farm practices;
Labor	% of the salaried workforce in the total farm workforce; number of salaried agriculture worker; number of family farmworkers; total of farm employment (including family and salaried workers).	Labor management is a major factor to explain crop choices
Land	First land access in the zone; Total area owned by the family; The total cropped area by year; % rent land of total cultivated land; Purchased land area; Land accessed within the settlement program.	Land access and land tenure condition the land security and, consequently, the farm activities.
Crop system	% area cultivated with fodders; % area with food crops; % area with cash-crops; trees' area; % maize area; % wheat area.	Crop pattern
Livestock	Number of Total Livestock Unit (TLU); Number of fattening animals; Number of dairy animals; % dairy crossbred (/total dairy animals); % dairy buffaloes (/total dairy animals); Number of small ruminants. The number of fowls.	Livestock management
Dairy activity	Animal product in EGP (Egyptian pounds); % dairy product; Milk yield per head; Dairy product in EGP/total fodder area; Total TLU per fodder areas.	Dairy specialization

Nitrogen Balances of Sedentary Farms With and Without Interactions With Mobile Pastoral Herds

In the present research, the environmental analysis is on the nitrogen dynamics and the quantification of nitrogen flows more precisely. Two environmental indicators were calculated at the farm level: the N balance and the N use efficiency. The apparent N farm-gate balances (Simon and Le Corre, 1992; Nevens et al., 2006; Vayssières et al., 2011) corresponds to the farm N surplus (NS) (in kg N ha^{-1} $year^{-1}$), i.e., a positive and high N balance corresponds to a soil fertility increase, but also with a risk of N leaching. It was calculated as follows:

$$NS = (N_{\text{in}} - N_{\text{out}})/UAA \quad (1)$$

The farm N-use efficiency (NE) corresponds to the farm's ability to use N resources (like manure or feeds) to produce N (edible products). A higher efficiency corresponds to a more efficient and sustainable farm. It was defined as the dimensionless ratio:

$$NE = N_{\text{out}}/N_{\text{in}} \quad (2)$$

Where UAA is the total Agricultural Arable Land (in ha), N_{in} (in kg N $year^{-1}$) is the sum of N in imported biomass: concentrate feeds, forages, animals, mineral fertilizers, and manure. N_{out} (in kg N $year^{-1}$) is the total amount of N in exported biomasses: animals, milk, and crop products.

N inputs to crops comprise on-farm produced manure, off-farm purchased cattle and chicken manure, and mineral fertilizers. In our case study, the on-farm produced manure was mainly from cattle or buffalo. The quantity was estimated from the seasonal amounts of the overall manure spread on the land, the size of the area concerned, and the type of manure (fresh or dry with straw). We estimated an average density of 750 kg fresh matter per cube meter for bovine manure. The amount of purchased chicken and bovine manure (mainly to large dairy companies in the zone) was estimated from the total number of carts purchased by the farmers, using the average amount of manure per cart.

The N contents of the different biomass types were calculated based on previous research (FAO, 1978, 2005). We used technical coefficients to convert the quantity of manure into kilograms of nitrogen (N). For purchased mineral fertilizers, we used their composition. Estimating the N input for purchased feed and the

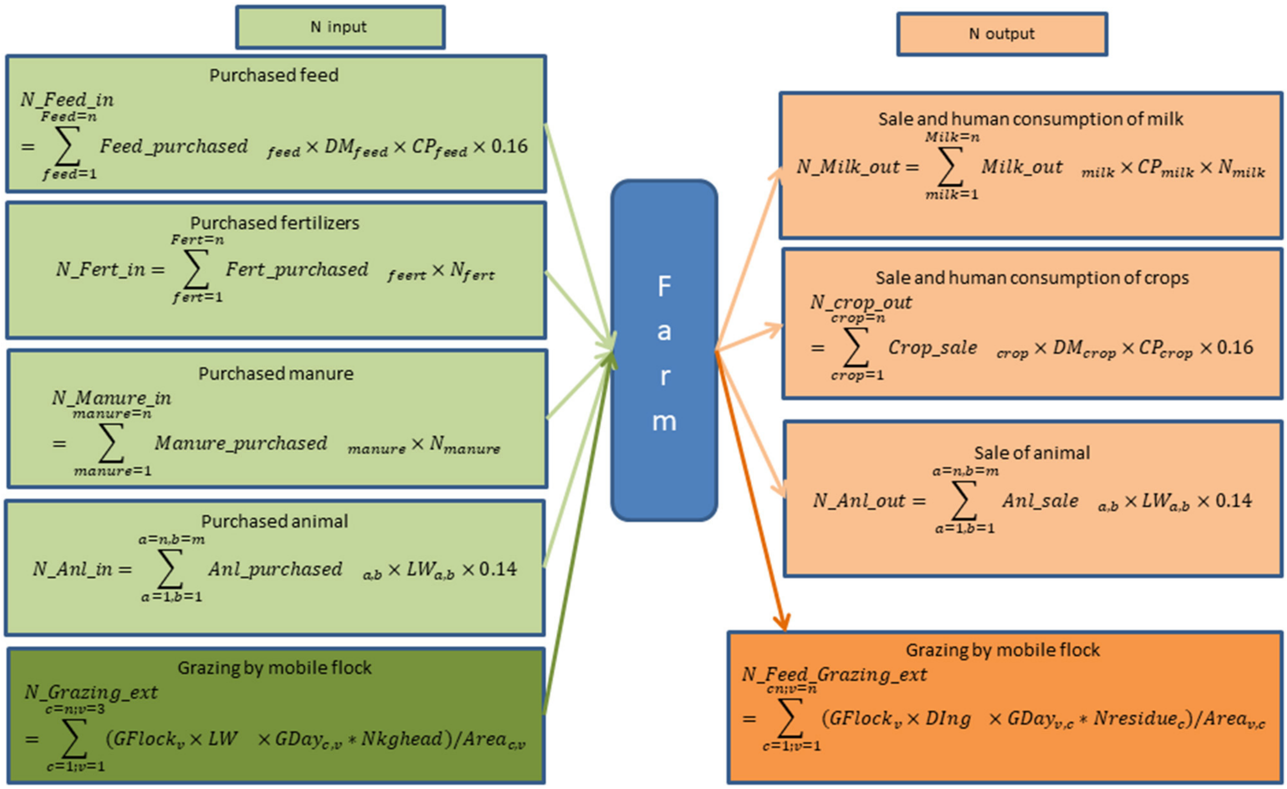

FIGURE 2 | Calculation of Nitrogen farm balance without (light color) and with (light and dark colors) taking account N flows due to grazing of mobile flocks. Feed: category of feed; Feed_purchased: quantity of feed purchased (kg yr l); DM: Dry matter intake; CP: crude protein content per kg; Fert: category of mineral fertilizer; Fert_purchased: quantity of purchased fertilizer per year; N: nitrogen content per kg; manure: type of manure (origin; mode of spreading); manure purchased: quantity of manure purchased per type; a: category of ruminant (buffalo; cattle; sheep; goat); b: category of age; An l_purchased: number of animal purchased; LW: live weight per head; Milk: category of milk product (by specie; by product: fresh, butter cheese); Milk_out: quantity of milk use; Crop_out: quantity of crop sold or consumed; crop: type of crop; Anl sale: number of head of animal sold; v: village for territorial nitrogen balance; c: residues crops; GFlock: grazing flock (in number); Gday: number of grazing days; Nkgh: eat nitrogen produced by head of the mobile flock; N residue: N content (kg yr^{-1}) of crop residual; Area: grazed crop area.

N output for the selling or self-consumption of crop products and residues required the use of a multitude of sources due to the diversity of crops and feeds at the different farms, such as Nijhof (1987a,b,c) and USDA (2015). The coefficients by crop products used in this study are in the **Supplemental Material a,b**. We estimated that 1kg of animal contained ∼0.5 kg of muscle with 28% protein for livestock. **Figure 2** represents the categories of input and uptake taken into consideration to estimate the N balance at the farm level.

In parallel, we assessed grazing contribution to fertilization levels based on the interviews with Bedouin herders in the Tiba area. We identified three grazing zones for three herder groups determined by their tribal memberships and their internal arrangements from the qualitative interviews. According to the cropland allocation in these zones, the herd size, and time spent in the zone, we estimated the quantity of organic manure provided by sheep and goats grazing in the Tiba zone. From the average amount of manure produced per head of sheep and goats, we estimated the N supply using coefficients from experimental trials on the quantity of defecation per day for each animal species and the estimation of nitrogen content (see Richard et al., 1989). For a sheep weighing an average of 32 kg live weight (LW), the daily ingestion of dry matter (DM) would be ∼460–780 g DM/day. With a digestibility of roughly 55.1%, the total defecated matter was estimated at 206–350 g DM. Assuming DM is one-third fresh matter, the average quantity of fresh matter of produced manure per head was 850 g/day per animal with a nitrogen content of 0.8%. For each zone (corresponding to one or two villages), we multiplied this coefficient by the number of animals and the number of grazing days described by the Bedouin herders to estimate the total N input in each grazing zone for 1year. Following the same method, we evaluated the N intake from crop residues based on a daily intake of 620 g DM/day/head.

RESULTS

Overview of the Diversity of Farming Systems in the NRL

The description of farming system diversity resulted from the MFA and clustering analysis to identify farm types from the farm survey database. The first analysis of variance shows a well-structured configuration based on the first two axes,

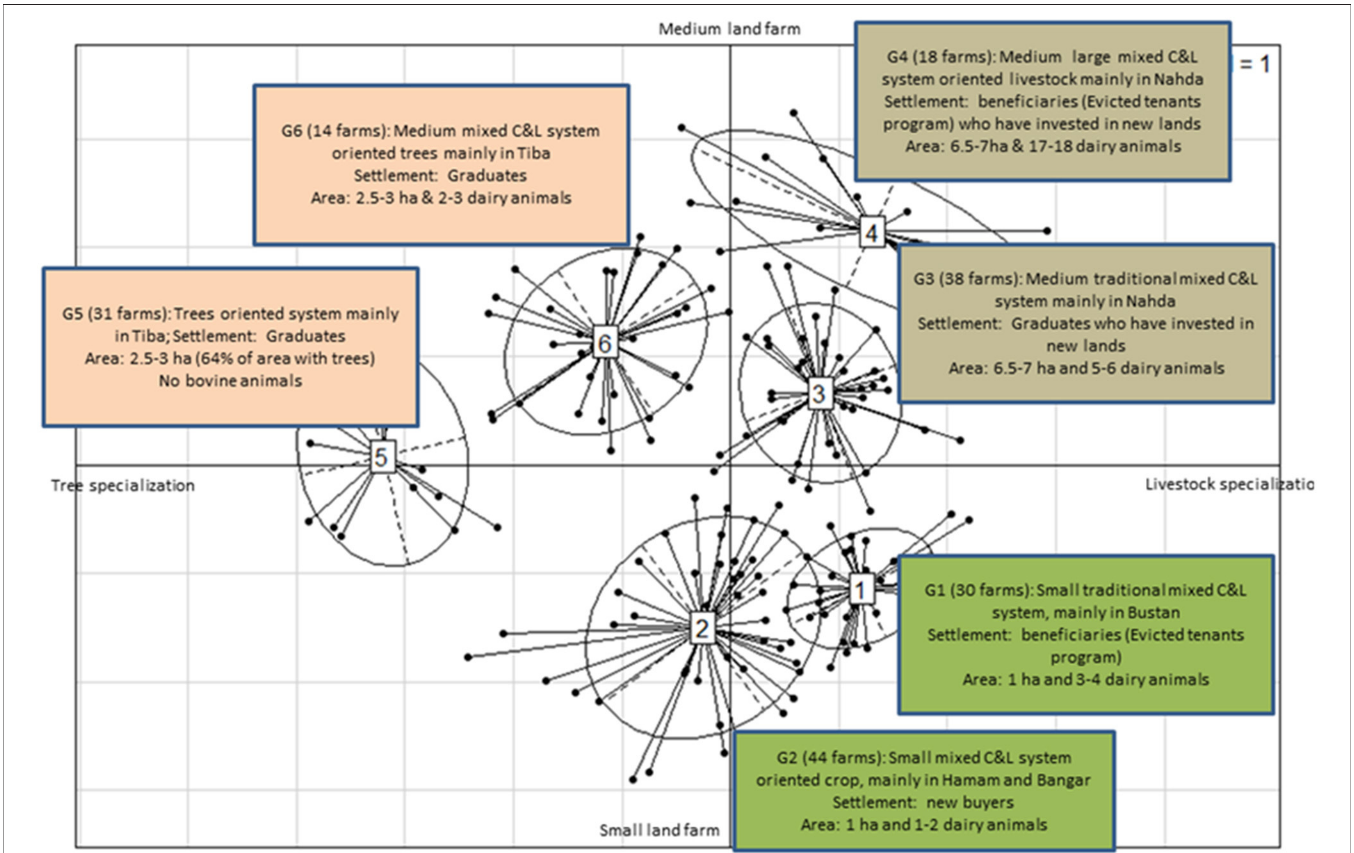

FIGURE 3 | Representation of the six family farming systems and their main characteristics in the first factorial plan (F1*F2). (1) C&L for integrated Crop and Livestock systems; (2) Each circle represents the confidence interval at 95% and the lines are the distance between each individuals and the center of gravity of each cluster.

representing 70% of the total variance (**Figure 3**). We observed a clear differentiation of the family farming systems according to land access on the first axis (37% of the Eigenvalue) and the tree *vs.* livestock orientated systems on the second axis (33.8% of the Eigenvalue). The agglomerative hierarchical classification allowed us to identify six clusters of family farm systems that were projected on the first factorial plan (F1*F2) in **Figure 3**.

Four of the six farm systems are considered as mixed crop-livestock systems from the Old NRLs (Groups G3 & G4 in **Figure 3**) and New NRLs (groups G1&G2, **Figure 3**). The medium and medium-large farm systems (Groups G3 & G4) started their activities in the 1970s and 1980s; most of these farm systems are located in the oldest land that was reclaimed in the 1960s (Nahda). The medium-sized farm systems (G3) are ∼2.5 ha in size and have 6 to 7 bovine animals, mainly consisting of crossbred cows for milk production. The large farms in Nahda (G4) have an average land area of 6.7 ha and ∼18 dairy animals, primarily consisting of 60% crossbred cows. The small-scale farms (G1) are located in the recently reclaimed lands from the 1980s (Hammam and Bustan). Another group comprises the non-graduate beneficiaries that obtained 1 ha within the Mubarack settlement program for evicted tenants. The other group (G2) includes new buyers who bought the land from other beneficiaries. For groups G1 to G4, the cropping system is based on a rotation of wheat and berseem (*Trifolium alexandrinum*) in winter with maize and various vegetables in the summer. Berseem and maize are mainly used for animal feed. Groups G5 and G6 (**Figure 3**) are tree-oriented farmers that recently obtained land in the New NRL, mostly in the Tiba zone and, to a lesser extent, in the Bustan zone. The majority of these farmers are University graduates who obtained 2 ha of land by auction at their arrival. Generally, these farmers opted for tree crops that would allow for more market opportunities. Group 5 is the most tree-specialized system.

Contribution of Livestock Activities to Crop Fertilization at the Farm Level

At this stage, we estimated the nitrogen flows entering cultivated plots for each farm type. The objective was to understand the relative contribution of livestock, through on-farm produced and off-farm purchased manure, to crop fertilization at the farm level without considering the manure from grazing by mobile herders. **Table 2** shows the relative contribution of produced and purchased bovine manure for each farming system. First, manure, including chicken and bovine manure, contributed up to 51% of the N supply in tree-oriented systems (G5), compared to the average 40% for the total farming systems. The lowest

TABLE 2 | Fertilization management at the farm level, without inputs from leased grazing (154 farms).

Farm types	G1	G2	G3	G4	G5	G6	Average
Sample	30	43	29	11	12	29	154
N input from bovine manure as a % of all the N used to fertilize crops from manure, including chicken manure	47%	46%	53%	54%	56%	49%	49%
N input from manure as a % of the total N used to fertilize crops, including mineral fertilizers.	40%	43%	35%	38%	51%	34%	40%
Farmers purchasing off-farm manure (% of farmers who purchased manure in the whole farmer population)	33%	47%	38%	18%	25%	38%	37%
The proportion of off-farm purchased bovine manure (% of the total used bovine manure, only for farmers who purchased bovine manure)	76%	80%	95%	100%	100%	70%	82%
N input (kg N/ha/crop cycle)	451	388	455	337	288	271	379
Cost of mineral fertilizer for food crops (US$/ha/crop cycle)	467	396	504	518	608	371	450
Cost of mineral fertilizer for fodder crops (US$/ha/crop cycle)	145	89	127	100	24	105	106

organic manure users were medium and large mixed crop-livestock systems in the Old NRL (G3 and G4 in the Nahda zone), suggesting that farmers settled in Nahda have already constituted their soil substratum over the 6 last decades of cultivation.

The origin of manure varied according to the zone and the farming systems. However, the proportion of bovine manure was approximately half of the manure input in the whole studied zone. About 37% of farmers purchased bovine manure (mainly from large dairy companies); among these farmers, the proportion of off-farm purchased bovine manure represented more than 70% of the bovine manure used on lands. In the tree-oriented farms (G5) and the large mixed farming systems (G4), <25% of the farmers purchased bovine manure. In general, most farmers are reluctant to buy bovine manure due to their fear of the dissemination of infectious diseases.

The N plot level inputs reached ∼379 kg N per ha and per crop cycle. This rate is extremely high. This desert environment is characterized by low organic matter in the soils, and this explained the manure's role as an organic matter amendment to the soil. The N input rate is the weakest for tree-oriented farms (G5 and G6), where farmers regulate fertilization according to perennial crops' N needs over the year. These results show the different roles of organic manure in this environment. The increasing gradient of manure use from the Old NRLs to New NRLs reflects the importance of organic manure in the first decades of desert land cultivation to build the soil organic matter capital in an arid desert with sandy soil (Enien et al., 2000; Malm and Esmailian, 2012).

The bovine manure purchase price was similar among the five zones, with a range of ∼11–13 US dollars per m^3 (**Table 3**). The chicken manure purchase price was the highest in Hammam, where the villages were distant from poultry farms. For mineral fertilizers, farmers in the Bustan zone paid the highest price per unit, mainly for ammonium nitrate and urea. In this zone, most farmers were obliged to cover their needs with mineral fertilizers from the market, which are more expensive than mineral fertilizers distributed through the cooperative. Some farmers in this zone preferred continued purchase of mineral fertilizers from their village of origin in the Nile Delta (Alary et al., 2018). In the other zones, the majority of the fertilizer input came from the local agricultural cooperative.

According to the interviewed farmers, the supply of bovine or chicken manure did not raise any problems due to the proximity of large specialized dairy farms or even multinational dairy farms with more than two thousand dairy cows. Only the limited supply capacity for mineral fertilizers by the agricultural cooperatives was systematically mentioned as a critical issue, knowing that the price doubled from that of the agricultural cooperative to that of the market for ammonium nitrate and urea.

Table 4 represents the nitrogen input and output at the farm level without considering grazing by mobile livestock. Mineral fertilizers and manure are the main N inputs (on average 84.1 and 12.6% of total farm N input, respectively), while crop products are the main output (on average 91.7% of total farm N output). The N input as mineral fertilizers and manure (both used to fertilize crops) exceed 2 to 3 times the N output from crop products, resulting in a positive N balance at the farm level that ranges from 221 to 488 kg N/ha/year. The farm N balances per ha are greater for mixed crop-livestock systems (G1, G2, and G3) than tree-oriented or specialized systems (G5 and G6, respectively); these higher N balances correspond to the higher purchase of mineral fertilizers for annual crops and feeds for livestock. N-use efficiencies range from 0.2 to 0.5. Efficiencies are higher for tree-specialized systems (G5) than livestock-oriented systems (G1, G3, and G4), which align with trees' capacities to uptake N from the atmosphere and soil.

Territory Level-Approach of N Flows and the Consequent Social Interactions Between Pastoral Herders and Farmers

Open interviews conducted with Bedouin herders in the Tiba area allowed us to understand the current tensions between pastoralists and farmers in the zone. In this territory, the majority of Bedouin herders originated from Wadi El Natrun. Their ancestors used to travel to the Tiba zone for rangeland when it primarily consisted of herbaceous and shrub vegetation until it was reclaimed for cropping. Thus, the Tiba zone is still perceived

TABLE 3 | Unit purchased price of organic and mineral fertilizers (in US$).

Zones	Bustan	Tiba	Hammam	Bangar	Nahda	Average
Bovine manure (US$/$m^3$)	13.5	10.6	12.6	12.9	11.2	12.1
Chicken manure (US$/$m^3$)	24.1	24.7	32.5	25.9	22.0	25.8
Ammonium Nitrate (US$/kg)	0.43	0.39	0.34	0.39	0.34	0.38
Sulfate ammonium (US$/kg)	0.23	0.23	0.22	0.29	0.44	0.28
Superphosphate (US$/kg)	0.18	0.14	0.15	0.14	0.13	0.15
Urea (US$/kg)	0.52	0.32	0.37	0.39	0.36	0.39

TABLE 4 | Nitrogen (N) flows, N balance, and N use efficiency at the farm level (154 farms), without inputs from leased grazing.

Variables	G1	G2	G3	G4	G5	G6	Average
Sample by farming type	30	43	29	11	12	29	-
N input (kg N) at the farm level							
Feed and forage purchases	46	20	28	29	1	14	23
Animal purchases	11	4	20	21	2	4	10
Mineral fertilizers	578	595	1099	971	541	788	844
Purchased manure	87	113	186	145	130	108	126
Total N inputs	722	733	1333	1167	673	914	1003
N outputs (kg N) at the farm level							
Animal sales	21	20	41	57	6	23	27
Animal product sales (e.g., milk)	7	4	11	23	0	6	8
Crop products	234	238	474	508	156	332	386
Total N outputs	262	261	525	589	163	361	421
N balance as input-output (kg $year^{-1}$)	461	471	808	578	510	553	582
N use efficiency at farm level (outputs/inputs) (Dmnl*)	0.4	0.4	0.4	0.5	0.2	0.4	0.4
N balance per hectare of arable land (kg N ha^{-1} $year^{-1}$)	442	488	422	263	257	221	367
N balance in kg per ha and per crop cycle (kg ha^{-1} $year^{-1}$)	215	175	213	132	134	108	165

**Dmnl, dimensionless.*

and considered by the Bedouin herders as their tribal territory. Three main tribes are always present in the zone: *Gwabis*, mainly located in the southeast of Tiba, and *Ali Ahmar* and *Snena* in the northeast (**Figure 4**). These three Bedouin groups lived in tents until the end of the 1990s and the establishment of the canal in the Tiba zone. In 2014, most Bedouin herders were obliged to settle in blockhouses at the borders of the Tiba zone, but they were not given access to a water supply, electricity at home, and social infrastructure (no school or health care center). Since settlers' arrival on the NRLs, Bedouin herders have followed the agricultural calendar for grazing land (**Table 5**). In most cases, herders and landowners orally negotiate the terms of grazing, specifying the duration of grazing and the total cost. The charge for grazing paid by the herders varies from 39 US dollar/ha for sugar beets up to 91 US dollar/ha for peanuts in 2014, knowing that a flock contains ∼360–400 head (**Table 5**). As the grazing fee is negotiated for each plot and between the herder and the landowner, this cost is similar throughout the zone depending primarily on the available grazing resources (on pastureland) in the Wadi Natrou (i.e., the surrounding pastureland around the settlement). Some herders arrange for extra land in other neighboring villages. However, they previously grazed mainly in two villages in the area.

In the Tiba zone, mobile pastoral herds grazed on crop residues from March to October, starting with sugar beets in March–April, wheat in May, bean in June–July, and peanuts from September–October (**Table 5**). During the winter season, they moved to open pastureland along the international Cairo-Alexandria Road (see **Figure 3**), and feed was complemented with concentrates. Some herders store crop residues for the winter to complete the animal diets from November to December.

We estimated the grazing effect by mobile herds in terms of nitrogen flows entering and exiting cultivated plots (**Table 6**). The calculation of these N flows used the data from grazing management (herd size, duration), as described by Bedouin herders, and the average quantity of ingested forages and produced manure per grazing animal. These flows represented from 9 to 34% of farm-level N input and from 25 to 64% of farm-level N output depending on the village, the cropping system, and the tree plantation stage. In our case study, due to the recent tree plantations that are not yet producing, N output level appears very important. So, N feed intake by mobile herds is higher than N manure excreted on the fields, resulting in a negative N balance (estimated from the difference between N manure excreted and N feed intake), ranging from −9 to −42 kg

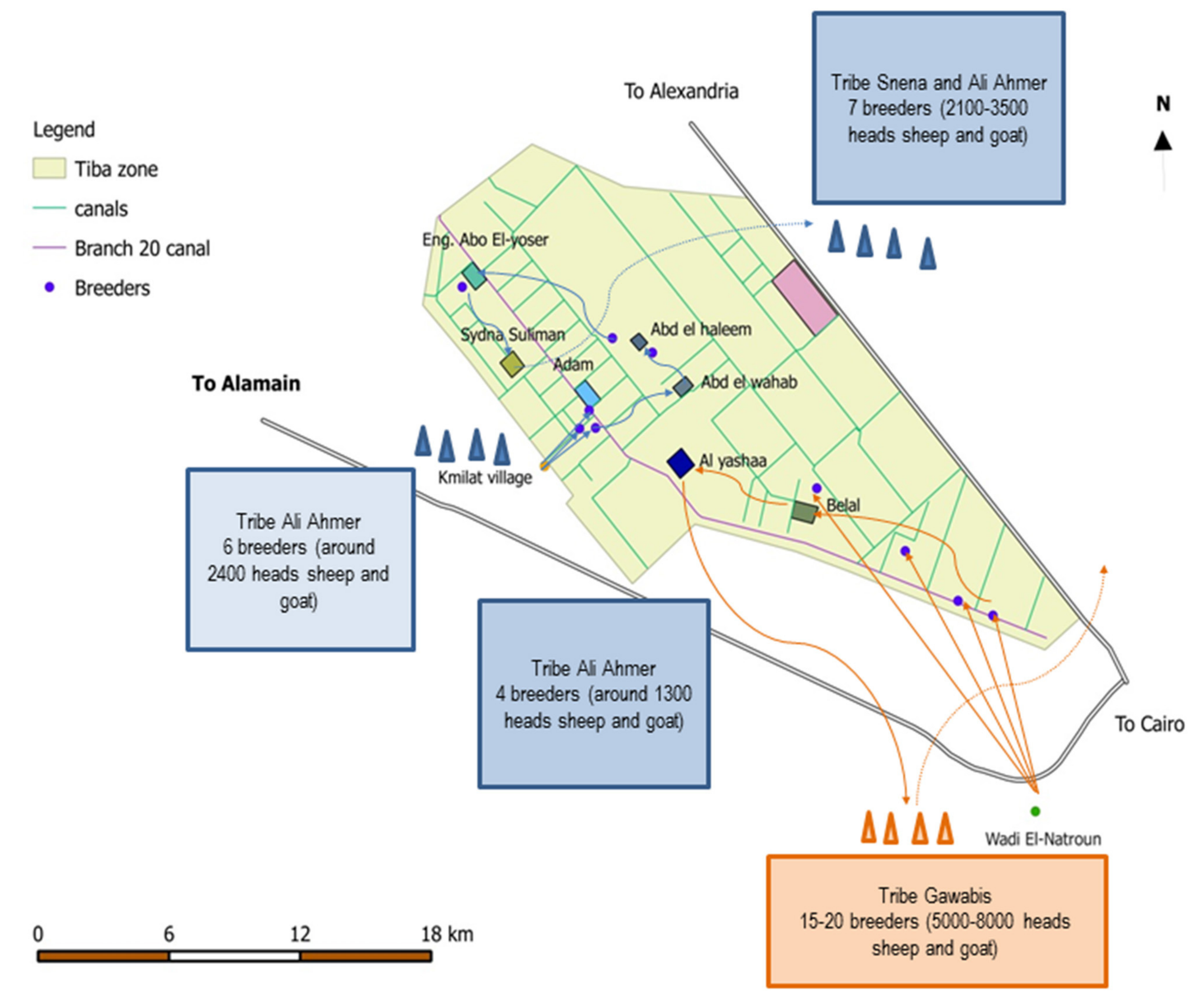

FIGURE 4 | Herd grazing circuits for the three Bedouins tribes in the Tiba zone (based on interviews).

TABLE 5 | Calendar of grazing period and total head manuring per season.

Months	First feed source	Range of cost payed by the herder (US$/ha per flock)	Grazing period (days per ha)	Number of sheep (head/ha/day)	Total manure input (kg N ha^{-1})	Unit feed cost (US$ per head and per day)
January to February	Rangeland	0				
March to April	Sugar beet	39–58	13.1	364	32.4	0.059
May	Wheat	73	3.0	562	18.2	0.187
June to July	Beans	72–86	6.6	805	45.6	0.084
August to October	Peanuts	60–91	22.1	419	52.2	0.088
November to December	Concentrates	-				

TABLE 6 | N flows due to grazing and N balance at the territory level taking account grazing practices.

Village	Adam village	Belal+Yashaa	Soliman
Descriptive characteristics of each sub-locations (grazing lands in ha and the animal stock)			
Mobile herds (Sheep and goats heads)	1,300	6,000	2,400
Surgarbeet (ha)	83	123	25
Bean (ha)	0	74	8
Wheat (ha)	53	364	204
Peanuts (ha)	34	235	60
Feed intake (in kg DM/ha/year)			
From sugarbeet	582	1,820	3,603
From Bean	0	3,002	11,188
From Wheat	461	306	219
From Peanuts	2,106	1,423	2,230
Tot ingested N by grazing flocks (kg N/ha/year)	43.2	91.0	231.4
% N farm outputs through grazing	25%	41%	64%
Manure supply (in kg FM/ha/year)			
To sugarbeet	797	2,495	4,939
To Bean	0	4,116	15,338
To Wheat	631	420	300
To Peanuts	2,888	1,952	3,057
Tot N supply by grazing flocks (kg N/ha/year)	34.5	71.9	189.1
% N farm inputs through grazing	9%	17%	34%
Grazing balance (kg N/ha/year)	−8.6	−19.1	−42.3
N balance at territorial level (kg N/ha/year)	223	213	190

1) the descriptive data gives the total land allocation by crops and the sheep and goat flock for each sub-location; 2) Feed intake in kg of dry matter per year is estimated from the total daily ingestion per the entire flock multiplied by the number of grazing days and divided by the grazing area; Total ingested N by grazing flocks is calculated based on the N content by kg DM of feed and the % N farm outputs and reported to the total N export per ha (composed of the N farm exit calculated in part 3.2); 3) The manure supply from the grazing flock is estimated by the total flock multiplied by the daily manure production divided by the number of grazing-days on the plots; Based on the N content by kg of fresh matter of manure, it is estimated the total N supply by the grazing flock per ha, and this is reported to the total N farm inputs estimated in this location;4) the grazing balance is the difference between the N supply and N exit from the grazing activity although the N balance at the territorial level is the difference between the total N input and output based on the farm and grazing practices.

N/ha/year. This N balance explains why the N balance at the territory level (ranging from 190 to 223 kg N/ha/year depending on the village) is lower than the N balance at the farm level (ranging from 221 to 257 kg N/ha/year depending on the farm type); the crop area in the current database corresponded to the cropping system in 2013–2014. With the rapid extension of tree plantations in the Tiba zone and the start of production of the plantations, crop residues grazing should be more restricted in the coming years by the landowners who will seek to protect their plantations. However, these preliminary results show how farmers can benefit from direct N-fluxed measurement to enhance N management.

According to the Bedouin interviewees, the main roles attributed by landowners to grazing herds were to clear the land and provide a supplementary income. On average, land leasing for grazing represented ∼200–220 US dollars/farm/year in 2015. The main reluctance of landowners is the risk of disease dissemination due to manure use, especially following the outbreak of foot and mouth disease in the area. However, farmers' mentioned benefits were that allowing herding keeps the land safe and, above all, prevents trouble or "looting" or "racketeering" with the Bedouin community. The majority of landowners said they feared trouble, land damage or racketeering caused by the mobile herders. Some of the farmers felt that one way to avoid social conflicts with Bedouins was to allow for grazing, consequently keeping the land safe.

DISCUSSION AND CONCLUSIONS

In African countries, manure represents a pivotal contributor to the fertilization of crops and reduced depletion of soil fertility (Rufino et al., 2007), and improving soil stability and its macro-structure (Bayu et al., 2005). Overall, nutrient cycling between livestock and crops through manure management and crop residue-based feeding systems are key-drivers to improve efficiency and sustainability of smallholder systems (Smith et al., 2009; Powell et al., 2010; Vayssières and Rufino, 2012; Alvarez et al., 2014). In the Mediterranean area, the intensification of cropping systems favoring tree plantations or cash crops along the coastline can favor the abandonment of livestock on farms and the relocation of livestock activities to the hinterland of either the mountains or non-irrigated plains. This farm specialization casts doubt on environmental sustainability, and it leads us to consider ways to strengthen relationships at the territory level between sedentary farms and mobile livestock systems (Alary et al., 2019). Therefore, studying the contribution of pastoral farming to agricultural systems at the territory scale allows us to better understand the possible synergies between these two systems through supporting sustainability-building social and ecological relationships.

Results reveal the critical role and contribution of livestock activity to crop fertilization and soil fertility maintenance, especially over the first decade of cultivation of the newly reclaimed desert land where manure is a significant source of N and organic matter. However, we observed a differential gradient of manure use according to the date of land settlement. In this new socio-economic environment, fertilization management varies according to the degree of integration of crop and livestock activities at the farm level based on the past experience (mainly knowledge and practices inherited from ancestors) of the new settlers coming from various agro-ecological regions of Egypt. At the territory level, the results reveal the multiple ecological and social services provided by diverse livestock systems to agriculture in Egypt's newly reclaimed desert land. Significantly, mobile herders' presence on the cultivated lands is as important in terms of support for social safety in the zone as it is in terms of valorizing residues. Moreover, the manure spread by animals contributes to soil structure maintenance. However, the input or output fluxes of nitrogen modify the final nitrogen balance at the farm level. This effect merits further attention from local or national agencies, especially those in charge of fertilization recommendations in the zone.

The system-gate approach based on the quantification of apparent N flows through farmers interviews gives a first calculation of the farm-gate N balance. These calculations highlight positive and high N balances in all farming systems (with an average N balance of ∼+367 kg/ha), that we can also observe in other parts of the world where farming systems use high levels of inputs as mineral fertilizers or concentrate feeds (Vayssières et al., 2009; Conijn et al., 2011). These high balances correspond to high N surplus and low N use efficiencies, resulting in a high risk of N losses to the environment, especially on sandy soils where N leaching can be substantial (Cameron et al., 2013). Soil N content measurements should confirm these potential risks. N flows quantification under real conditions, including soil N leaching and N gaseous emissions, would be valuable to confirm environmental risks and enhance soil fertility dynamics through manure management practices.

Finally, this study calls for socio-technical support to better understand nutrient and organic matter supplies and dynamics, especially the use of mineral fertilizers combined with manure, in accordance with soil management practices and social practices around livestock management social organization in the zone. Nutrient management is not only a matter for agronomists. Soil fertility maintenance as a livestock function involves a new way of thinking about the whole system, integrating territory-level dynamics, and calling for a renewal of livestock policy development that focuses on food and income production and supports good social and environmental relationships and opportunities for synergy.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Materials**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

VA contributions to the conception or design of the work/field work, drafting the work or revising it critically for important intellectual content, and write the paper. AA-N contributions to the conception or design of the work and provide approval for publication of the content. MO contributions to the conception or design of the work and contribution to farm data analysis. ID contributions to the conception or design of the work for approaching pastoral systems. JV Agree to be accountable for all aspects of the work related to the approach of nitrogen balance at the farm and local level, and co-write the paper. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.500437/full#supplementary-material

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