Indigenous and Scientific Knowledge of Soil Regulation Services, and Factors Effecting Decision-Making in Agricultural Landscapes in the Terai Plains of Nepal

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Abstract. Rapid degradation of soil regulation services is a growing concern for agricultural producers worldwide, with the potential for adverse impacts on agricultural productivity, food security, and livelihoods. Yet, data integrating observations of soil nutrient and physical status with farmers' knowledge of soil fertility is lacking, while landscape-level empirical assessments remain limited. In this paper, it is argued that a deeper understanding of the benefits and trade-offs of management practices currently employed by farmers to secure soil nutrients could help to promote improvements in natural resource management, agricultural productivity and efficiency. Using the case of the Central and Western Terai Plains of Nepal in 2012–2014, rice-cultivated soil parameters were estimated, and 354 respondents were interviewed to determine the cropping systems, soil nutrient status and risks, indigenous soil classification systems, and key biophysical, institutional, economic and risk perception factors effecting decision-making. Findings reveal farmers are acutely aware of the main causes of soil degradation and until today, these issues continue to be of critical importance. To counter this degradation, farmers employ a diversity of landscape-level practices to secure optimal crop yields and soil nutrients. However, farmers have limited access to agricultural extension services and scientific monitoring and apply fewer mineral fertilisers than previously reported. Additional investments are required to optimize farmers' practices and soil regulation services, such as cooperation for knowledge innovation systems, public/private extension, organisation for co-management, integrated nutrient management, and private forestry on farms. The case illustrates local knowledge and incremental efforts to adapt to emerging risks remain the foundation to implement spatially targeted conservation measures and design adaptive land use plans.

Keywords: Soil regulation services · Soil conservation · Indigenous knowledge · Agriculture · Decision-making · Soil fertility status

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1 Introduction

1.1 A Subsection Sample

At the global scale, nearly 30% of terrestrial lands have agricultural crops or planted pastures as a dominant land use [1], which can profoundly impact environmental systems and ecological functioning across the whole landscape [2, 3]. Today, despite increased political attention in recent years and research investments in enhancing sustainable agriculture, land conversion to agriculture rapidly continues, modifying habitats and degrading ecosystems [4]. Many least developing countries still rely heavily on their primary sector (i.e., agriculture) as an engine of economic growth and food security [5]. Yet, the majority of actions largely do not take into account the need to customize recommendations to particular agro-ecological conditions, local knowledge systems and cultural preferences [6]. Land managers, planners, conservationists and community development practitioners require information on current practices, and factors influencing farmers' decision-making to secure optimum soil nutrients for sustainable yields and livelihoods.

Across Asia, there are potentially significant gains for improved soil management. Particularly in Nepal, 78% of the workforce depends on agriculture and demand continues to grow. However, in the last 20 years in Terai Plains of Nepal (hereon referred to as the Terai) - an area stretching 1360 km from East to West with the Himalayan Churia foothills to the North and India to the South [7], yields of rice have remained static or gradually declined, and soil fertility decline is a common concern of farmers [8–11]. Over-utilisation and erosion of marginal lands is widespread, given a growing population, rising land values, scarcity and fragmentation, tenure insecurity and short-term responses to productive needs [9, 12, 13]. Correspondingly, since 2000, the Ministry of Agricultural Development's financing in the agricultural sector has retracted by 30%, fertiliser subsidies have dropped by 55% [14], national fertiliser production is at a deficit (in 2010 the country required 100 000 metric tons, producing 30 000), and rural access to fertilisers is frequently restricted by cross-border strikes over fuel imports [16]. One consequence of these challenges and associated poverty faced by many rural farmers is that much of the young generation migrates to India, to East Asian or Persian Gulf countries, to supplement family incomes [13].

There have been suite of multi-stakeholder private-public partnerships, government, and international and non-governmental aid assistance projects aimed at implementing soil conservation initiatives, such as inter alia soil amendment and testing (e.g., via Nepal Agricultural Research Council (NARC), District Agricultural Development Offices, Ministries of Forest and Soil Conservation, cooperatives, and micro-credit institutions); planting woodlots, hedgerows, or set aside areas or bio-engineering for slope stabilisation (e.g., via LI-BIRD, CARE International and agroforestry extension services); terracing (e.g., International Centre for Integrated Mountain Development); improving irrigation efficiency (e.g., Institute of Development Enterprises); flood protection (e.g., International Water Management Institute); installing and maintaining canals (e.g., World Health Organisation); and rainwater conservation ponds (e.g., World Wide Fund for Nature, Community Forestry User Groups). However, many initiatives have not yielded expected results. This is in part due to difference between the expectations of farmers and managers of public programmes (including extension agents, trainers, conservationists) of the ability of these programmes to make yield improvements, along limited national ownership in programs, duplication of efforts, and affordability of capital and agricultural inputs [10, 16–18].

Research over the last 20 years in Nepal has studied soil fertility enhancement and conservation techniques such as green manuring [20], legume intercropping [21], crop residue retention and tillage [22]. Various studies have examined farm-level factors affecting the adoption of new technologies under different climate and socio-economic scenarios (e.g., [19, 23, 24]). Another significant body of literature has documented perceptions of soil fertility, soil classification systems [25–28], and indigenous knowledge [29], yet recent evaluations have not been conducted. Yet, the necessary data is not available for the Central and Western zones of the Terai Plains of Nepal. Few studies have– integrated observations of soil's nutrient status or physical characteristics with farmers' knowledge of soil regulation services [11]. Landscape-level assessments remain limited [30]. We also have an insufficient understanding of what influences farmers' actual decision-making processes in relation to programme participation and adoption of recommended practices [19].

To address this fundamental knowledge gap, this study aims to assess soil nutrient and physical status in combination with farmers' knowledge of soil fertility at the landscape-level and unpack what factors influence farmers' decision making in the Terai Plains of Nepal. Specifically, chemical and physical soil surveys were conducted on forty rice-cultivated farms. Farmer interviews (n = 100), and focus groups with 140 farmers (n = 354) were used to determine cropping systems (i.e., landholding sizes, crop combinations, stocking rates, and labour time), indigenous classification of soils. Finally, key informant interviews and focus groups were used to investigate current and potential soil conservation measures (i.e., perceived benefits, trade-offs, opportunities, and constraints for adoption and level of use), and key factors determining farmers' decision-making. Results offer recommendations for effective land-use planning.

2 Materials and Methods

2.1 Study Area

Sampling was carried out in four landscapes between May and September 2012 in 22 village district committees (VDCs) within 40 wards: (1) four VDCs in Madi Valley, Chitwan district (N27°28.305′ E084°17.244′, 204masl), (2) six VDCs in Rupandehi district (N27°35.414′ E083°31.180′, 138masl), (3) six VDCs surrounding Gohari, Dang district (N27°50.783′ E082°30.068′, 256masl) (referred to hereafter as Dang), and (4) six VDCs in the Deukhuri Valley, Dang district (N28°03.086′ E082°18.712′, 597masl) (referred to hereafter as Deukhuri) (Fig. 1, Appendix 1). The climate is a warm-temperate zone, with a mean annual temperature of 24.6 °C (min = 18.2 °C, max = 31 °C), and rainfall ranging from 1000 to 2100 mm/a [31]. Elevation ranges from 108 to 658masl, and the main soil type is Dystrochrepts [32]. The region hosts a population of 708,419, with notable geographic, climatic, ethnic and social diversity [33]. Land use is largely subsistence-based, including cultivation, home gardens, mixed crop-livestock systems, non-timber forest product harvesting, river boulder and gravel mining, aquaculture, residential, and tourism. Rice (*Oryza sativa L.*) is the main staple crop, grown predominantly for local consumption during the monsoon season, and holding high economic, social, and cultural importance [34, 35].

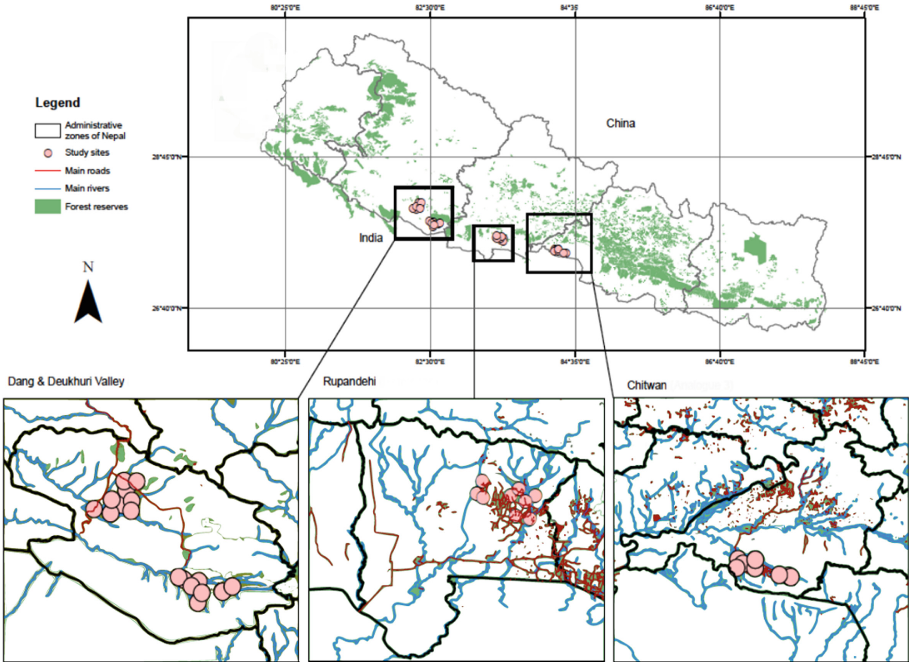

Fig. 1. Map of study area in the Central and Western zones of the Terai Plains of Nepal (*n* = 40 villages). Within each region, ten villages sampled were distributed across the hydroshed catchment within 200 km^2, surveyed using regional topographical maps of Nepal (1:25 000) sourced in 2012 from East View Cartographic Inc., Minneapolis in the USA, and the Ministry of Land Reform and Survey, Government of Nepal in Kathmandu. Farmers cultivate rice on 5.78 ± 2.33 ha (mean, SE) in the monsoon season (May – September) in terraced landscapes [43].

2.2 Cropping Systems

Data were available from farmers in forty villages and key informants (n = 354). Working with local partners, in each landscape the research team first met with the head of each village and key informants to describe the project objectives and obtain input on the study design[1]. The survey was then trailed with 40 respondents. One lead surveyor and three trained enumerators administered structured interviews with the self-identified

[1] Permissions to conduct the fieldwork from local communities were obtained, objectives were stated upfront to ensure respondents understood the purpose of the use of the information, and confidentiality/anonymity was ensured. Access to study sites was facilitated through NARC and a local organisation Friends Service Council Nepal, with ethical permissions rendered by the University of Oxford.

household head in each homestead or farm, in Nepali over 90 min between 06h00 and 09h00. To determine the cropping systems, questions were asked about landholding size, crop combinations, stocking densities, livestock use and fodder collection time and distance. As far as possible, the sample was stratified by age (25 to 67 years), sex (72.5% male, 27.5% female), caste (n = 9) and livelihood (n = 15). Representation by each caste group was taken into consideration during sampling, as traditionally there is some variation in farming practices following the Hindu caste system in Nepal (Tiwari, Sitaula et al. 2008). Respondents represented the castes of the Tharu (32.5%), Brahmin (27.5%), Chhetri (12.5%), Magar (7.5%), Dalit (7.5%), Gurung (5%), Sanyasi, Dura, and Teli (ea. 2.5%).

2.3 Soil Parameters

The procedure of in-situ soil analysis followed standard procedures using Hannah Instruments Professional Agricultural test kit (HI-3896, UK) [36, 37]. Abiotic chemical and physical indicators were used as proxies for soil regulation services. pH was measured using a colorimetric (halometric) indicator with a range of 4 to 9 pH (single increments). Available N was measured using a manual colorimetric method with Ned reagent. Available P was measured using a colorimetric method with ascorbic acid. Available potassium (K) was measured using a turbidimetric method using tetraphenulhorate reagent. Texture was assessed using a soil texture triangle test of particle size, indicating how much organic matter the soil can hold. Soil parameters were taken one month after planting and nutrient replenishment by manure or chemical fertilisers to the fields. Soil samples were taken randomly from ten fields in each landscape. Ten samples per field were obtained from the Ap horizon (0 to 15 cm) and amalgamated. To assess the indigenous soil classification system, farmers were asked to describe their system that forms the basis for crop selection, and agronomic cultural practices [32, 38, 39].

2.4 Perceived Factors Impacting Soil Quality Decline

We followed Bewket [40] and Vignola, Koellner et al. [23] by asking farmers about what they considered to be the salient risks to soil health, how this effects levels of production, erosion or input requirements, and if "general soil health" had changed in the last ten years. These factors were then ranked by importance. Salient risks were judged to be observable, well-known, to have an immediate effect, or high exposure on- or off-site [41, 42].

2.5 Strategies to Increase Soil Fertility, and Factors Determining Farmers' Decision-Making

Heads of households associated with the farms where ecological sampling was conducted, were asked to identify soil conservation practices, perceived benefits and trade-offs for soil regulation and production, opportunities and constraints for adoption, and level of use. Socio-economic, cropping system, and time-use data was also collected. Following interviews, transect walks were made on farms and the landscape within

250 m of homesteads to directly observe the soil's physical condition, and engage farmers in informal discussions about management practices. Informal interviews and focus group discussions with 140 farmers (a subset of the 354 respondents) provided additional information about farmers' perceptions, strategies and aided triangulation.

2.6 Policy Recommendations

A diverse range of interest groups (n = 112) were interviewed about constraints to soil conservation practices, the current role of local and extra-local institutions in promoting technologies, and effective policy recommendations. A total of 174 key informants were interviewed, including agricultural extension workers, academics, policy makers and conservation/development workers from the ward to international level (Table 1, Appendix 2, See [43]).

Table 1. Summary of representation from key informant interviews (n = 174), 14 operating internationally, 20 nationally, 11 regionally, 18 at the district level, 31 at VDC level, and 18 at the ward level. *(VDC: Village District Committees, INGOs: International non-governmental organisations).*

Level	No.	%	Sectors	No	%	Institution type	No	%
Local (VDC)	31	27.01	Agriculture and food security	40	35.71	Community representative	29	25.89
National	20	21.26	Development	36	32.14	Government	22	19.64
Local (Ward)	18	18.39	Environment and climate	20	17.86	NGO	17	15.18
District	18	12.64	Risk reduction	6	5.36	Private sector	15	13.39
International	14	12.07	Finance and business	6	5.36	INGO	14	12.50
Regional	11	8.62	Education	2	1.79	Research	12	10.71
			Gender and health	2	1.79	Donor or media	3	2.68

3 Results

3.1 Cropping Systems

Across the study area in the Central and Western regions of the Terai, the mean landholding is 5.12 ± 4.78 ha/household (mean, SE), and land has been continuously cropped for 6.56 ± 1.63 years. Twenty-three crop types were identified. Rice (*Oryza sativa L.*) comprises the main crop cultivated in 88% of fields, commonly intercropped with lentils *(Lens culinaris*) (45%), followed by maize (*Zea mays*) (65%), wheat (*Triticum* *aestivum*) (48%), and mustard (*Rassica juncea*) (38%). Seventy-eight per cent farm vegetables, herbs and trees are grown as cash crops[2]. Few farmers cultivate fruits, which are typically imported from India and sold in local markets. Crop variety selection depends on the grain and by-product yields (e.g., bedding for livestock stalls, feed or fuel). Alongside the cultivation of crops, the average household owns 12.55 livestock units, which is notably higher than that of the Mid-Hills (four livestock units) [44]. Goat and buffalo are the most common livestock, owned respectively by 53% and 50% of farmers, while 28% own cows and poultry, and 20% own oxen. Livestock are commonly reared for manure (by 73% of households), meat or milk (67%), manure for fuel (47%) and plastering using manure (43%), transport (20%), or risk insurance by sale (20%) (Table 2). Maintain livestock is a labour-intensive activity, on average, farmers walk 0.85 ± 0.9 km/day to collect fodder, specifically: 4.2 ± 2.39 h/day to collect fodder for goats, 2.71 ± 2.27 h/day for buffalo and 1.9 ± 0.89 h/day for cows. Livestock also have cultural value.

Table 2. Landholding and stocking density during the monsoon season in rice-based systems. Farmers cultivate the largest land area in Deukhuri (5.9 ± 4.93 ha), while farmers cultivate the smallest land area in Chitwan (3.6 ± 2.6 ha) *(M: mean; SD: standard deviation; SE: standard error).*

	Chitwan, Madi Valley				Rupandehi				Dang, near Ghorahi				Deukhuri Valley, Dang			
	n	M	SD	SE	n	M	SD	SE	n	M	SD	SE	n	M	SD	SE
Farm size (ha)	10	3.6	2.6	0.87	9	0.78	6.99	2.33	10	5.9	4.93	1.64	10	5.2	4.26	1.42
Livestock heads																
Buffalo	10	13	1.42	0.45	10	110	1.15	0.37	10	6	1.07	0.34	10	23	2.21	0.7
Small ruminant	10	33	2.98	0.94	10	220	2.94	0.93	10	16	2.22	0.7	10	88	11.9	3.76
Ox	10	0	0	0	10	11	0.32	0.1	10	7	0.95	0.3	10	10	1.94	0.61
Cattle	10	4	0.97	0.31	10	88	1.4	0.44	10	7	1.25	0.4	10	4	0.7	0.22
Pig	10	0	0	0	10	00	0	0	10	1	0.32	0.1	10	5	0.97	0.31
Poultry	10	58	8.66	2.74	10	00	0	0	10	92	25.2	7.96	10	43	6.7	2.12
Duck	10	34	8.58	2.71	10	00	0	0	10	10	3.16	1	10	2	0.63	0.2

3.2 Soil Parameters

Soil Texture, pH and Macronutrient Levels. The mean soil pH in the wet season is 6.42 ± 0.81 (Table 3), meaning the soils are generally acidic, largely due to the acid-based parent material and inappropriate application of acidifying mineral fertilisers over

[2] For example, vegetables grown in the study area include potato, cauliflower, beans, cabbage, tomato, onion, ladyfinger, bitter guard, cucumber, bottle guard, carrot, lemon, garlic, peppermint, sunflower, chilli and coriander.

extended periods [45]. Nitrogen is typically at trace-low fine concentrations, with the lowest levels found in Rupandehi and the highest in Deukhuri. This can be attributed to continuous cropping of high N-feeding plants, and reduced fallowing [21]. Phosphorous is typically at low-medium concentrations, with the lowest levels found in Rupendehi and the highest in Chitwan. In most sites, potassium is at trace-low concentrations, except in Chitwan where it is medium grade. Physical analysis indicates soil texture is dominated with clay, except in Deukhuri where the soil is dominated by fine sand.

Table 3. Analysis of soil sampled (0–15 cm depth). Macronutrients are graded according to trace (1), trace-low (2), low-medium (3), medium (4), medium-high (5) and high (6). Values are represented as the mean and standard error.

Parameter	Chitwan	Rupandehi	Deukhuri	Dang	All sites
Soil pH	6.6 ± 0.07	6.61 ± 0.36	5.83 ± 0.3	6.8 ± 0.12	6.42 ± 0.15
Soil total available Nitrogen (N)	1.8 ± 0.29	1.33 ± 0.17	2.3 ± 0.42	1.5 ± 0.22	1.77 ± 0.16
Soil total available Phosphorus (P)	3.1 ± 0.41	1.89 ± 0.35	2.4 ± 0.36	2.67 ± 0.22	2.51 ± 0.2
Soil total available Potassium (K)	3.9 ± 0.1	2.33 ± 0.24	2.2 ± 0.34	2.67 ± 0.45	2.8 ± 9.18
Stony texture (>2 mm) (%)	2.00	4.00	12.00	0.00	4.50
Coarse sand (2–0.02 mm) (%)	17.50	1.63	8.50	5.00	8.16
Fine sand (0.2–0.02 mm) (%)	32.00	15.63	44.50	19.30	27.86
Silt (0.02–0.002 mm) (%)	15.50	10.63	14.00	33.80	18.48
Clay (<0.002 mm) (%)	33.00	68.13	21.00	41.80	40.98

Indigenous Soil Classification System. Farmers have their own criteria for distinguishing local soil types to evaluate production potential, species composition and agronomic cultural practices. Khrishna describe: *"It is not about the amount of land we have, it's the quality and the fertility of the land"* (27/05/2012, Beora, Rupandehi). Systems have been developed and transferred orally over many generations, as follows:

Colour: Colour is a partial indication of organic and mineral content, pH levels, age of the soil, parent material, and structural stability. For example, farmers typically consider darker or black soils more fertile, with a higher carbon and moisture content and cation-holding capacity. Red soils are generally considered high in iron and aluminum, low in P, and are an indication of a long-leaching process.

Topsoil Texture: Texture, the size of individual particles, is a partial indication of the supply of nutrients, water, and air, that are necessary for plant root development and soil workability. For example, heavy-textured and stony soils require higher labour inputs for ox/hand ploughing than light-textured soils. Land close to riverbanks is considered sandy and therefore unstable, with a higher risk of flooding and sedimentation. Silt is considered good for cultivation, as it is softer and fertile, but has poor water retention.

Depth: Farmers consider deep soils (>1 m) to generally have a higher water-holding capacity, and appropriate to plant crops with deeper roots.

Slope and Altitude: Flat lands often have lower likelihood to erode, and therefore are considered more suitable for cultivation, but low, waterlogged land is susceptible to nutrient leaching.

Proximity to Forests: Farmers consider land closer to densely or vegetated areas to have higher fertility.

3.3 Perceived Factors Driving Soil Fertility Decline

Seventy-four percent of respondents perceived a decline in soil fertility over the last ten years, according to indigenous soil classification attributes. The most highly ranked underlying reason reported by 89% of respondents for this was deforestation. Large-scale deforestation is driven by greater demand for building material, energy, agricultural use, and grazing. Deforestation causes severe soil erosion, reducing productivity in soils upstream, and sedimentation in water downstream [46]. Second, soil is contaminated by excess and indiscriminate application of mineral fertilisers (e.g., Murate of Potash (MOP), Diammonium Phosphate (DAP)) or pesticides (e.g., Goxamin, Thaitan, Krioloxy, Metacide). Excess inputs increase soil hardness, break down soil structure, reduce organic matter, and consequently cause long-term productivity decline. Much of the N applied to rice crops is lost by volatilisation, denitrification, and leaching [22, 47]. Third, organic fertiliser availability is declining. Livestock is less desirable to keep with increased direct costs. Fodder availability is declining with heightened land scarcity and forest restrictions. Moreover, urbanisation and international labour migration are lowering succession rates [9]. Consequently, farmers do not have a sufficient labour force and time to collect fodder or plough manually with oxen, buffalo, or hand. The majority of farmers (70%) are transitioning to mechanized tractors. Approximately 38% reported increased intensity of rainfall in short periods resulting in topsoil runoff, landslides and sedimentation of fields along river courses. Rainfall events are followed by extended periods of drought reducing vegetative cover, soil water infiltration capacity and moisture loss [48]. River-mining for building material exacerbates flooding intensity, widens river courses, increases agricultural land inundation, and irrigation water turbidity. Pests, pathogens and weed growth are other salient risks.

3.4 Strategies to Increase Soil Fertility

Farmers improve precision and manage risks through incremental adaptation and innovations, based on rich historical antecedents [49]. In total, 33 practices are employed individually or in combination. Appendix 3 lists the top 25 of these non-exclusive/interrelated practices. Beneficial practices are defined as those that supported the continued ability for the soil to sustain crop or animal growth over time through efficient recycling and provision of nutrients and water.

Nine methods of soil amendment are widely employed, using mineral fertiliser, farmyard manure (FYM), compost, green manures, decaying or living mulching, urine and faecal sludge, ash, vermicomposting, forest soil, or combined applications. To improve soil structure, stability, soil-water retention, slow water velocity and reduce nutrient loss, seven methods are used, i.e., farmers fallow, branch-pack, construct gabions, restrict river mining, post-harvest cover crop, and create ditches or bunds. To control erosion, farmers plant native woodlots and wildflower strips, contour hedgerows, or riparian buffer strips around farms, homesteads, riverbanks and communal areas. The most commonly grown plants to prevent erosion are *Dendrocalamus strictus*, *Leucaena leucocephala*, *Panax pseudo-ginseng*, *Cynodon dactylon* [50]. To increase soil organic matter (SOM), farmers reduce and amend the timing of tillage, or the ratio of chemical to organic fertiliser, retain crop residue, or selectively apply pesticides, fertilisers or herbicides.

To improve SOM levels, decomposition, and convert atmospheric N to usable ammonia N for plants many farmers intercrop (i.e., planting two or more temporary/permanent crops as a mixture of unstructured crops) [21, 51]. In 50% of cases a combination of at least three crops are cultivated, while in only 8% of cases one crop is planted. For example, farmers intercrop cereals with legumes, sesame, mustard or shade-grown crops between crop rows, underneath the main crop, or along farm boundaries.

Fifty-two percent of farmers rotate crops (i.e., cultivating single crops (type/variety) on a land parcel in one season, followed by another single crop in the following season [12]. For example, farmers rotate monsoon rice with winter wheat, cowpea, mustard, bamboo or chilli. Others rotate between land uses (e.g., crop-pasture-aquaculture). Rotation regenerates nutrients, reduces pest infestations, suppresses plant fungal and nematode pathogens in the soil, and allows farmers to cultivate crops with different water requirements. Farmers also commonly shift to new rice varieties every two to three years. In addition, 49% of farmers employ terracing with the land under irrigated *khet* or rainfed *bari* terracing being dependent upon the landform position and slope.

Consistent with evidence from other parts of Nepal (e.g., Pilbeam, Mathema et al. 2005, Paudel 2015), farmers traditionally place a high value on the use of FYM for organic fertiliser: 78% prepare and apply FYM. Farmers recognize the quality of the faeces of different animal species, and how the net movement of N from non-agricultural land to agricultural land varies according to fodder and livestock type. FYM is typically collected using household biogas compost pits, in-situ manuring, zero-grazing, and manually collecting untreated heaped compost.

Four of the seven types of chemical fertilisers used in Nepal are used in the study area [52]. Diammonium Phosphate (DAP) is most commonly applied by 60% of farmers at a rate of 0.11 kg/ha/season. Urea is applied by 53%, at a rate of 0.09 kg/ha/season, which is notably lower than reports of urea application in the Mid-Hills of 15 to 115 kg/ha/season [27]. Application rates of Murate of Potash (MOP) (0.004 to 0.034 kg/ha/season) and Zinc (0.014 to 0.027 kg/ha/season) are also much lower than previously reported [21]. Ammonium Sulphate (AS), Single Super Phosphate (SSP), Ammonium Phosphate Sulphate (APS) are not applied. However, these averages disguise the wide range of actual application rates, and fertiliser is often only applied to a portion of the total cropped area [27]. The ratio of organic to chemical fertiliser is 49:51, and is often combined (e.g., FYM with urea, DAP/MOP, residue, ash, green manure, or kitchen waste).

Ten species are used for green manuring (i.e., mixing plants into the soil), particularly on cultivated areas of rice and vegetables, which are considered to increase macronutrient levels. These include *Panax pseudo-ginseng*, *Bengal pogostemon*, *Achyranthes aspera*, *Justicia adhatoda*, *Syzygium cumini*, *Albizia lebbeck*, *Artemisia indica/vulgaris*, *Leucaena leucocephal*, and *Dendrocalamus strictus*. *Musa sapientum/paradisiac* is grown to increase the soil potassium content. *Sesbania* is a local grass grown to fix N and decompose quickly [50]. Previous studies have also shown the leaves of these plants have a higher macronutrient content than that of FYM compost (Table 4) [28].

Table 4. Estimated faeces voided, fertilizer applied and plant species used to enhance soil quality the monsoon season across all sites. **Adapted from Sthapit (1989); Khadka and Chand (1987); Subedi (1989).

Estimated faeces voided	Kg/ha/day	Estimated fertiliser application rates	Kg/ha/season	Plant species commonly used to enhance soil fertility	Percentage (%)		
					N	P	K
Buffalo	45	Diammonium Phosphate	0.11	*Justicia adhatoda* (Asuro)	4.3	0.9	4.5
Goat	13.75	Urea	0.09	*Artemisia indica/vulgaris* (Tite pate)	2.1	0.2	4.1
Cattle	15	Murate of Potash	0.02	*Albizia lebbeck* (Kalo siris)	2.9	0.7	2.6
Poultry	0.74	Zinc	0.02	*Sesbania sp* (Dhaincha)	1.5	0.3	2
				Compost	0.4	0.3	0.3

3.5 Factors Determining Farmers' Decision-Making in Soil Conservation Management

Farmers recognize the following interrelated factors to be most salient in determining the voluntary adoption of soil conservation interventions. There are many complex aspects of decision-making processes that evolve with changing societal values over time, but these are not addressed here [53].

Perception of Risk: Practices are adopted with benefits on-site (e.g., SOM, macronutrients, macro/micro-fauna composition/activity, soil structural integrity, slope stabilisation, texture, sediment profile) and off-site (e.g., reducing watercourse sedimentation or velocity) and which reduce risk (also shown in [54]).

Knowledge and Experience: Producers are more likely to take up a practice who have experience on their own land (territorial exposure) for a prolonged period of time (history of use), and if benefits are widely known. Access to new, clear technical knowledge that is crop/season/location-specific encourages adoption (also shown in [55, 56]).

Biophysical Factors: When determining conservation measures, farmers pay attention to crop requirements (e.g., seedling germination, crop growth rate, water), site-specific management history (e.g., origin of the land, seed bank, vegetation remnants), infrastructural access (e.g., roads, input suppliers, markets), and climatic conditions (e.g., precipitation, temperature, solar radiation, wind, evapotranspiration, soil moisture content) (also shown in [42]).

Economic Factors: Farmers are more likely to adopt practices which increase monetary utility or value, reduce production costs, or raise or stabilize yield of marketable goods (also shown in [56, 57]).

Complementarity (e.g., multiple uses such as shade, income generation with by-products or surplus products) and competitiveness (e.g., employing practices which minimize competition for nutrients, light, water or use) also determine whether practices will be adopted (also shown in [42]).

Institutional Factors: Practices are more likely to be adopted by farmers with good social capital for knowledge transfer, who participate in soil conservation programs, or have support from extra-local government agencies, NGOs, or communal institutions for technical training, demonstration, field visits, inputs, subsidies, financial transfers or enforcement of preventative legislation. Farmers with clear property rights or long-term rental agreements are more likely to adopt sustainable decisions regarding resource use (also shown in [58]).

4 Discussion

4.1 Comparison Between Indigenous Soil Classifications and Scientific Parameters

As this study has shown, Nepali farmers hold substantial knowledge on soil evaluation and classification, as revealed by their capability to categorize the soil's production potential based on various criteria (e.g., colour, texture, depth, slope, altitude, proximity to vegetated areas), and incrementally adapt to multiple stressors to improve the soil condition. Nepali farmers also have strong rationales for sustaining diverse soil conservation practices. It is critical to determine this knowledge because this it largely determines management approaches. However, despite knowledge and practice, more support is required to optimise soil fertility.

While some of farmers' observations were in close agreement with the level of the scientific observations, such as N and texture, for other parameters farmers lack accuracy, such as identifying the exact amounts of pH and minerals needed by their crops. Farmers do not have detailed information about the amounts of macro- and micronutrients in the soil, nor specific crops and appropriate inputs that are suited to particular soil types. Their diagnostic parameters are based mainly on visible, topsoil attributes of the soil. And changes in soil properties are only fully grasped when reductions in yield and growth performance are observed [59].

The limits to indigenous knowledge highlight the need for supplementation with scientific assessments, which can allow for the detection of changes not readily observable. In particular, scientific observations provide information on chemical properties and micronutrients below the soil surface. However, in the year prior to the survey, only 10% of respondents had access to scientific analyses of soil, partly because diagnostics are costly and time-consuming, and the diversity of soil classifications and taxonomies are difficult to grasp. Moreover, only 20% of farmers had contact with extension agents representing the District Agriculture Development Office, mandated to provide information of soil quality measurements and appropriate application of fertilisers. Therefore, beyond post hoc annual assessments of yield and soil regulation service, the effectiveness of conservation practices is not clear. For farmers who do have information access, blanket recommendations for fertiliser application often disregard soil type, or vary greatly depending on sources [60]. Meanwhile, NARC suggests most farmers do not adhere to recommended rates, timing and type of fertiliser application, and many do not have access to inputs: in the study area, application rates of fertiliser are lower than found in previous studies (e.g., [27, 61]).

Recognizing these barriers to information access and appropriate management practices, local knowledge can advance the scientific knowledge and vice versa. Indigenous classifications should be seen to complement, and not substitute scientific methods [59, 62]. Complementarity of the two knowledge systems can develop new paradigms for sustainable development. Looking forward, cooperation between researchers, government extension agents, agrovets, and farmers needs to be enhanced to improve diagnostic tools. To be successful, on-farm adaptive research needs to use a participatory approach, employing simple local or regional language when measuring soil parameters [59].

4.2 How Do We Incentivize Soil Conservation Practices at the Farm and Landscape Scale?

Farmers in the Terai require more scientific assessments of soil, and training in composting practices, integrated nutrient management, FYM production, cultivation of N fixing crops, and drainage techniques for saturated soil. To increase the uptake of soil fertility management practices, and woodlot cultivation, pluralistic approaches to extension services (e.g., volunteer extension agents, agrochemical dealers, commercial outgrower schemes, e-extension) could address strained staffing and financing, and should be accompanied by demonstration (e.g., [63]).

Although farmer-to-farmer learning is considered helpful [64], surveys indicated the exchange of information between farmers could be improved. Membership to farmer organisations has been shown to have a positive effect on adopting new practices via access to social capital, labour-sharing and credit [65]. However, technical assistance is needed to build in organisational, literacy and financial capacity, and meet registration requirements [66]. Shared learning and analyzing trade-offs within/across communities, can be promoted via knowledge sharing days, farmer exchanges, or experimental plots [67].

Cash and other livelihood incentives for soil management practices need to be at least equivalent or higher than other livelihood options. For example, farmers need to understand the economic benefits of using FYM for organic fertiliser, rather than for plastering, sale or fuel. To increase cash incentives, the sale of organic-certified products has potential to promote healthy soil, rich in organic matter, nutrients and microbial activity. Communities are organizing themselves to reduce marketing costs, centralize sales, lobby government, or independently construct roads, bridges, irrigation systems and storage systems. However, technical assistance is needed to promote local multi-product markets, link producers directly to national/international buyers, manage commercial contracts, improve product quality, credit access, post-harvest processing and handling [68]. Developing local markets to procure livestock can increase stocking rates and FYM production, as could zero-grazing zones, stall-feeding and fencing, distributing fodder seedlings, and installing cement troughs [69]. Furthermore, integrating private forestry on farms into the national forestry program could reduce pressure on forest and soil resources (and reduce respiratory/eye ailments associated with indoor fuel wood usage), as could up-scale decentralized renewable energy (e.g., biogas, solar energy) [70]. At the same time, community conservation concessions could encourage communal woodlot cultivation, with appropriate attention paid to compliance and enforcement.

All of these interventions and associated diverse actors operate within particular institutional and regulatory contexts. For example, bilateral negotiations between the Nepali and Indian governments could help control the import and use of low-grade chemical fertilisers, currently sold on the black market [14]. However, an analysis of which goes beyond the scope of this paper. At the same time, there is a need to ensure that financial incentives do not crowd-out intrinsic motivations for good soil management practices or lead to perverse outcomes, such as in the case of the Northeastern Chinese Sloping Land Conversion Programme which resulted in unintended impacts such as afforestation in marginal lands [71]. Aligning national food security and conservation aims is one way to reduce perverse subsidies that harm ecosystem service provisioning [72, 73].

Given the retraction of public spending in agriculture, innovative mechanisms are clearly needed to source additional streams of capital. Benefits have been shown in the coexistence of diverse public, private and mixed funding streams. Taxes are unlikely to be available, given that 48.4% of Nepal's population lives on less than $3.10/day (2011), while collection is challenging [74]. Payments to farmers for ecosystems service provision via tradable rights could offer some funding, and have been around for some time[3]. However, the nature of spatially heterogeneous landscapes in the Terai, with high temporal variability, means quantifiable regular tracking and verification at a national scale is complex, requiring specialized equipment, expertise and clarification of property rights.

[3] For example, the Gold Standard Biogas Voluntary Emissions Reduction pilot project, implemented by WWF since 2015, and the Reduced Emissions from Deforestation and Degradation plus (REDD+) readiness process was implemented by the Ministry of Forests and Soil Conservation and others since 2010.

5 Conclusion

This study aimed to assess soil nutrient and physical status in combination with farmers' knowledge of soil fertility at the landscape-level and unpack what factors influence farmers' decision making in the Terai Plains of Nepal. Evidence presented provides local indigenous knowledge and scientific information at the landscape scale of a wide range of soil fertility management practices currently employed in the Terai Plains of Nepal. The combination of knowledge systems may provide a means to engender participatory agricultural land use planning and agro-technology transfer [62, 75]. Incremental adaptation and innovations to emerging changes are based on rich historical antecedents. Decision-making is informed by risk perception, knowledge, experience, complementarity and competitiveness, as well as multiple economic, biophysical and institutional qualities valued by farmers, who form part of social-ecological systems. This study provides a deeper understanding of the suite of soil management practices currently employed, to help to optimise precious resources and time, and incorporate flexible, adaptive land management, and recognition of the contribution that farmers make to conservation. Initiatives could be replicated in other areas with similar contexts – thereby contributing to the reconciliation of food production and conservation and the ability of farmers in the Terai Plains of Nepal to meet multiple Sustainable Development Goals, such as 2 (zero hunger), 3 (health and wellbeing), 12 (responsible consumption and production),13 (climate action), and 15 (life on land).

Future longitudinal research is needed to evaluate the effectiveness of practices both in terms of landscape-outcomes and specific interventions, including soil amendment technologies that are affordable, reduce dependence on external inputs and are appropriate for changing climatic conditions (e.g., bio-char, bacteria/fungi, vermiculture). Future research could investigate the information farmers require regarding landscape configurations for intercropping, contour planting, planting native woodlots, or set-aside habitat in farmed landscapes. Research could also study targeted "fit-for-purpose" practices that, inter alia, reduce erosivity, increase nutrient cycling, efficiently use space, improve water retention and slope stabilisation, and suppress weeds and pests. Additionally, research could also investigate the information farmers require on the most appropriate types/lengths of crop rotation, or crop cultivars (e.g., genetically modified organisms, wild relatives. Finally, future research could explore relationships between farmer age, education, exposure to training, access to government subsidies, and the uptake of new or short-/long-term practices.

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