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Transition to agroforestry significantly improves soil quality: A case study in the central mid-hills of Nepal

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ABSTRACT

Agricultural intensification continues to be a major threat to sustainable development in mountain regions of the world since it is largely associated with lower soil fertility, increased soil erosion, pollution and eutrophication of water bodies, reduced biodiversity, and livelihood challenges. Agroforestry, the purposeful cultivation of trees and crops in interacting combinations, has the potential to provide environmental benefits and to contribute to livelihood security, and is receiving increasing attention as a sustainable land management option. Whereas many studies highlight general positive environmental and socio-economic effects of agroforestry systems, effects of the transition to agroforestry practices have rarely been quantified and studied in detail, in particular in Nepal. This paper analyses alterations of soil properties after the adoption of agroforestry practices in a typical mid-hill region of Nepal. Three agrosystems were compared with a special focus on soil fertility: (i) a mature, fully developed agroforestry system (AF); (ii) the predominant conventional system (CS) characterized by monocropping; and (iii) a system that has been in transition to AF for two years (TS). The results show significant differences in soil pH, aluminium content, base saturation, electric conductivity, organic matter and nitrogen content, and cation exchange capacity between AF and CS soils, indicating a higher soil quality and more fertile soil conditions in the AF soils. The contrasting soil quality has to be largely attributed to the differing land management practices. After two years of transition, the TS soil data already show a convergence towards the AF values in several parameters. This study gives quantitative evidence that agroforestry systems have the potential to significantly enhance soil quality and long-term soil productivity, with positive effects appearing shortly after the conversion from conventional monocropping systems.

1. Introduction

The vast majority of Nepal's population in rural areas continues to depend heavily on the agricultural sector for income and employment opportunities although the share of agriculture in the gross domestic product (GDP) has fallen significantly from 72% in 1975 to c. 35% in recent years (Upadhyaya, 2000; IIDS, 2013). However, agriculture still employs c. 75% of the total labour force, thus representing the driving engine of economic growth in Nepal, and at the same time constituting the key for poverty alleviation. But the growth of the agricultural sector underachieved in recent decades despite agricultural intensification.

Several agricultural development programmes had been initialized during the first decades of the 20th century aiming to promote the extension of agricultural activities (Raut et al., 2011) and providing information on improved seeds, chemical fertilizers and agro-tools (Dahal, 1997). The total production of cereals greatly increased indeed between the 1960s and 1990s, but in contrast to other countries this increase has to be attributed to the enlargement of the area under food crops (in particular in the Terai region) rather than to an increase in their yields. Actually, the per capita cereal production declined because the annual cereal production increase rate of 2.3% (between 1980 and 1990) could not keep pace with the population growth rate of 2.5% (HMG/NPC, 1994). Poor irrigation facilities, dependence on fluctuating monsoonal precipitation under rainfed conditions, lack of marketing infrastructure and networks, inadequate supplies of key inputs, and a weak extension and research system are among the most prominent causes for low agricultural growth rates.

Agricultural performance during the past two decades is still lagging behind expectations in spite of the formulation and implementation of various agricultural plans and policies such as

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the twenty-year Agriculture Perspective Plan (1995), the National Agriculture Policy (2004), or the Three Year Interim Plan (2007/08–2009/10). More than half of Nepal's districts are unable to produce sufficient food to meet the basic needs of the people with 60% of households in these districts – located largely in the mountain physiographic region and the mid- and far-western development regions – experiencing food insufficiencies (Upreti, 2010).

Nevertheless, the total production of agricultural commodities more or less steadily increased from 11.8 million metric tons in 1998/99 to 18.9 million metric tons in 2010/11, with a particularly high gain in cash crops such as potatoes, vegetables and fruits (CBS, 2012). The increased agricultural output as well as the extended variety and number of crops reflect a recent agricultural intensification process with an increasing commercialization of the prevailing subsistence production system. The general shift from a subsistence-based farming system to an intensified farming system has been facilitated by government extension services and a proliferation of NGOs. The adoption of agricultural inputs such as fertilizers, pesticides and hybrid seeds, and improved irrigation and road network systems essentially contributed to changes in cropping patterns, use of agro-chemicals, irrigation and mechanization (Dahal et al., 2009; Raut et al., 2011). However, the agricultural intensification process threatens the sustainability of upland farming systems in the long run since it can have serious environmental consequences at various spatial scales – increased soil erosion, lower soil fertility and reduced biodiversity at the local scale, pollution of ground water and eutrophication of rivers and lakes at the regional scale, and impacts on atmospheric constituents and climate at the global scale (Matson et al., 1997). Several case studies from the mid-hills of Nepal highlighted higher amounts of nutrient loss, soil erosion and a general soil quality degradation as a consequence of the shift to intensified farming systems (Gardner and Gerrard, 2003; Shrestha et al., 2004; for a review see Raut et al., 2010). E.g. Tiwari et al. (2008, 2009a,b),),) compared traditional and commercial cropping patterns and assessed higher amounts of soil and nutrient losses, and a deterioration of soil physical and chemical properties. Exchangeable soil K deficits, higher potential for soil acidification (decline in base cation content), and significant increases in available soil P (due to excess P input) after several years of agricultural intensification in irrigated sites were reported by von Westarp et al. (2004). Higher concentration of N, P, and K in water bodies near intensification areas due to excessive use of chemical fertilizers was found by Dahal et al. (2007).

A promising option to counteract unsustainable agricultural intensification is the adoption of more integrated farming systems such as agroforestry. Commonly understood as an integrated approach of producing food, fodder, fuelwood and/or timber by combining trees and shrubs with crops on agricultural land, agroforestry has the potential of providing additional benefits such as preventing soil erosion, maintaining soil fertility, enhancing water quality, conserving biodiversity, and mitigation of climate change by carbon sequestration (Young, 1997; Jose, 2009; Nuberg et al., 2009; Powlson et al., 2011; Nair and Garrity, 2012). In Nepal, agroforestry systems generally involve agricultural crops, tree crops, and livestock (Amatya, 1996), but have evolved from simple agriculture into a range of farming systems with varying degrees of integration (less integrated, semi-integrated, and highly integrated agroforestry) including specific agroforestry practices such as home gardens, silvo-pastoral and forest-based systems (Amatya and Newman, 1993; Dhakal et al., 2012).

An increasing number of studies highlight positive socio-economic and environmental effects of agroforestry systems in Nepal (e.g. Garforth et al., 1999; Schmidt-Vogt, 1999; Acharya and Kafle, 2009; Biggs et al., 2013; Pandit and Paudel, 2013) and in South Asia in general (e.g. Maikhuri et al., 1997; Yadav et al., 2008; Sharma et al., 2009; Saha et al., 2010; Bhadauria et al., 2012), very few of them, however, provide precise facts and figures on changes of environmental parameters after the transition to agroforestry practices. In particular, alterations of soil physical and chemical parameters in the course of transition to agroforestry systems have received little attention. Neupane and Thapa (2001) explored differences in soil fertility between agroforestry and non-agroforestry fields in the mid-hills of Dhading District. Further respective studies are hardly available. In view of this knowledge deficit, the objective of this paper is to analyse the effects of transition to agroforestry practices on soil properties with a special focus on soil fertility. As the maintenance of soil resources is critical in the agricultural landscape of Nepal's mid-hills, we want to examine on the basis of quantitative data whether agroforestry practices result in improved soil quality and contribute to soil conservation and thus to enhanced sustainability and resilience of land use. We hypothesize that differences in land management practices between conventional and agroforestry systems are reflected in the short term by more favourable soil conditions as indicated by soil chemical parameters such as soil pH, base saturation, electric conductivity, organic matter, nitrogen, phosphorous, and cation exchange capacity.

2. Materials and methods

2.1. Study area

The study was conducted on the upper slope of the Kolpu Khola watershed in the area of Kaule village (1860 m a.s.l.), Okaharpauwa Village Development Committee of Nuwakot District (Fig. 1). The study area represents a typical mid hill region of Nepal with respect to land management conditions. It has a subtropical

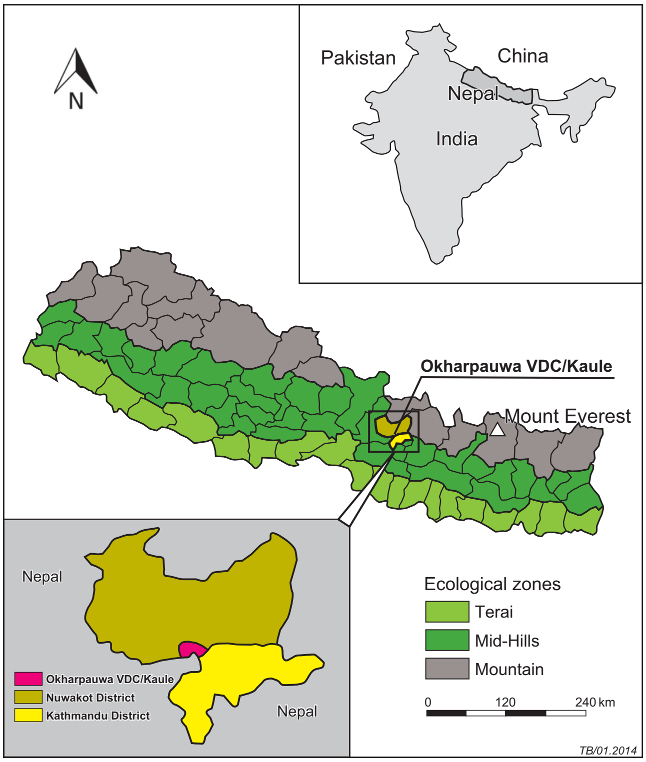

Fig. 1. Study area in the mid hill region of Nepal.

monsoon climate with an annual precipitation of 2822 mm (recorded at the nearby climate station Kakani, 2064 m a.s.l.) and highest monthly rates in July and August (unpubl. data provided by the Department of Hydrology and Meteorology (DHM), Government of Nepal). The paved road Kathmandu – Trisuli passes the village at a distance of 30 km to the capital while the linear distance is c. 15 km. In Nuwakot District, 69% of the economically active population is occupied in the primary sector. The mean farm size amounts to 0.59 ha with six head of livestock per household on average (Intensive Study and Research Center, 2010). In general, soil erosion, eluviation of nutrients and reshaping of terrace fields for the purpose of strawberry farming represent the major problems of land use in Kaule (cf. Bista et al., 2010).

The sampled plots are located within an altitudinal range of 1600–1800 m a.s.l. This section of the watershed area consists of moderately steep to very steep slopes (inclination 20–36%), in consequence cultivation takes place on terraced land. Soils of two reference profiles, one at the lower end, one at the upper end of the altitudinal range are classified as Haplic Cambisols (IUSS Working Group WRB, 2007).

2.2. Comparison of three agrosystems

In Kaule, current agricultural land use comprises three agrosystems (see Tables 1 and 2):

- A mature, fully developed agroforestry system (AF), which was adopted on one land holding 15 years ago. The AF farmer grows a multitude of trees and shrubs; the family cultivates a huge variety of crop species, including fruit trees and legume species, and uses compost and animal manure solely instead of mineral fertilizer. Algae from a fish pond are used as additive to the compost. According to Nair (1985), this AF can be classified as mixed dense agrosilvopastoral system with homegarden characteristics. Collection of liquid manure and dung from farm animals has major importance.
- The predominant conventional system (CS) characterized by mono-cropping and a strong dependency on external inputs notably firewood, green fodder, fertilizer and pesticides. Farmers cultivate strawberries as cash crop, which is an important contribution to their income. In addition wheat, maize and paddy is grown in the CS which is the case in all three systems in varying intensities. The CS is not free of some well known AF elements such as fruit and fodder trees on terrace risers and fertilizing with farm yard manure. However, there are considerable differences to AF in terms of cropping intensity, use of farm inputs, tree density and tree species diversity (Tables 1 and 2).
- A system that has been in transition to AF for two years in 2010 when sampling took place (TS). In addition to CS crops, farmers introduced in varying quantities and with varying success up to 11 fodder plant species, 4 non timber forest products, 7 vegetable species and 9 fruit tree species on TS terraces in 2009 and 2010 to become more independent from external resources and to increase the number of products for both subsistence and market sale (Tables 1 and 2). The TS is located on land holdings of 15 families who have been participating in an agroforestry program, initiated and long-term supported by the Nepalese-German NGO Kaule e.V.

Crop rotation and double cropping is common practice in all systems, permanent cultivation of strawberries as cash crops is dominant though at many CS farms. Fields with strawberries and vegetable cash crops are irrigated regularly, in dependence on season and water availability. The small-scale pattern of AF, CS, and TS in Kaule offered the opportunity to conduct comparative studies on spatio-temporal development of soil properties, and to infer implications of different agrosystems with respect to sustainable management of soil resources.

2.3. Soil sampling and analyses

We randomly selected 8 mid-sized terraces within each agrosystem. On these 24 terraces, 4 composite soil samples were taken from each terrace – 2 samples from the plough layer (0–20 cm) of the fields and 2 samples from the terrace risers (Table 3). A stainless scoop was used to sample 500 cm^3 soil from shallow test pits. In order to minimize differences in soil conditions due to diverging bed rocks or other abiotic or biotic determinants which are not directly related to cultivation, the sampling design was applied to soils within a small area of 0.5 km^2 in a narrow altitudinal belt including AF, CS, and TS land. This preselection reduced the number of available farms for CS and TS samples to 7. As there is only one mature, fully developed AF farm in the study area it was not possible to allocate the 8 AF replicates on different farms. However, the randomization resulted in samples with a

Table 1
General characteristics of the compared agrosystems (based on field data and unpubl. data by A. Schick).

	AF	CS	TS
System established in	c. 1995	Old and common system; strawberry monoculture since c. 1990	2008
Spatial position of annual crops	On terrace fields	On terrace fields	On terrace fields
Spatial position of perennials	On terrace risers; some trees on terrace fields	On terrace risers; some terraces without any perennials	On terrace risers; some trees on terrace fields
Main location of green fodder source	On farm	Majority of fodder is collected in surrounding areas, e.g. community forests[a]	
Soil tillage	Hand hoe	Ploughing with ox + hand hoe, depending on availability of ox, terrace size and accessibility[a]	
Double cropping	Yes	Yes	Yes
Crop rotation	Yes	Yes	Yes
Mineral fertilizer + pesticides	No	Urea, DAP and pesticides	AF practices without mineral fertilizer use were learnt in AF trainings.
Liming	No	No	No
Green manure	No	No	No
Irrigation	Fields with strawberries (mainly in CS) and vegetable cash crops are irrigated regularly in all systems		
Rice field management	No rice fields	Irrigated	No rice fields

[a] Not differentiated between CS and TS because data is available at farm level only.

Table 2
Specific data of sampled terraces and associated farms (based on field data and unpubl. data by A. Schick).

		AF (farm no. 1)	CS (farms no. 5–8)	TS (farms no. 2–6)
Total land area		0.69 ha	0.88 ha[a]	
Area assigned to AF		0.69 ha	0.08 ha[a]	
Percentage of land assigned to AF		100%	9%[a]	
No. of goats		15	10.5[d]	
No. of buffaloes		2	1.5[d]	
Fish pond at farm		Yes	No	No
Use of algae from fishpond as additive to compost		Yes	No	No
Use of ash		Additive to compost	Application directly on the field	Application directly on the field
Addition of needles to compost		No	No	No
Addition of leaves to compost		Yes	Yes	Yes
No. of cultivated crops (2011)		25	10.4[b]	Additionally to the CS crops, farmers introduced up to 4 non timber forest products, 7 vegetable species and 9 fruit tree species at the TS terraces in 2009 and 2010.
No. of cultivated crops for own nutrition (2011)		25	7.9[b]	
No. of cultivated crops for market sale (2011)		23	4.7[b]	
Income from plant production (2010)		76,040 NPR	38,836 NPR[a,c]	
% From strawberry production (2010)		5.9%	53.8%[a,c]	
Expenses spent for all kinds of fertilizer + pesticides (2010)		5485 NPR	9824 NPR[a,c]	
Expenses spent for manure (2010)		5485 NPR	6690 NPR[a,c]	
Expenses spent for mineral fertilizer + pesticides (2010)		0 NPR	3133 NPR[a,c]	
Quantity of mineral fertilizer purchased (2010)		0 kg	64.3 kg[a,c]	
At investigated terraces	Crops (+ perennials inside field), grown when sampling took place	Chilli + Taro/Cucumber (+ Apricot)/Maize/Peas (2 fields)/ Taro (2 fields)/Tomato	Chilli/Maize/Millet/Peas/Radish/ Rice (2 fields)/Strawberries	Asparagus + Peas + Beans/Chilli + Taro/ Maize/Peas/Peas (+ Apricot, Guava)/ Peas (+ Kiwi)/Strawberries/Tomatoes
	Total no. of tree & shrub species	34	16	37
	Mean no. of tree & shrub species	10.8	4.9	12.3
	Mean no. of tree & shrub individuals	28.5	9.9	51.0
	No. of nitrogen fixing tree + shrub species	5	1	5
	No. of Leguminosae tree/shrub species	4	0	4
	Individuals of nitrogen fixing trees & shrubs	26	7	88
	Leguminosae tree/shrub individuals	23	0	84
	Individuals of *Alnus nepalensis*	3	7	4
	No. of fodder tree species (according to Panday, 1982)	11	6	12
No. of investigated terraces	With perennial species at terrace riser and inside fields	1	0	2
	With perennial species at terrace riser only	7	6	6
	Without perennials	0	2	0
Mean tree + shrub cover of sampled terraces		22.0%	7.2%	11.4%
Mean total vegetation cover of sampled terrace risers		92.8%	77.4%	86.6%

[a] Not differentiated between CS and TS because data is available at farm level only.
[b] Data not available for farm no. 8.
[c] Data not available for farms no. 3,7,8.
[d] Data not available for farms no. 2,5,7.

wide spatial spread over the AF land. In addition, we sampled terrace risers, which are not intentionally managed, as uncultivated controls to compare the basic matrix of all 3 systems. All samples were taken at the end of the main harvest period and monsoon season between mid-September and mid-October 2010.

Soil samples were air dried at 40 °C and analysed by standard analytical methods at the Department of Geography's soil laboratory (University of Hamburg). Fine soil was separated by sieving with a 2 mm mesh and analysed for physical and chemical properties. pH was measured potentiometrically in a 0.01 M $CaCl_2$-suspension (referring to NAW, 1997). Electric conductivity of the saturation extract (EC) was derived from EC of soil solution in H_2O, measured by a conductivity probe (DVWK, 1995). The samples were tested for anorganic carbon by HCl (10%) (Ad-hoc-AG Boden, 2005). Total C (C_t) and total N (N_t) were analysed by dry combustion of grinded samples and measuring thermal conductivity with a CN analyser (TruMac CN630, LECO). Organic C (C_{org}) and organic matter (OM) were derived from C_t supposing the conventional ratio of 1:1.72 of C_{org} to OM, on the assumption of anorganic C-free samples ($C_t = C_{org}$). To measure effective cation exchange capacity (CEC) and single cation concentrations by ICP-OES (Optima 2100 DV, PerkinElmer), a percolate using Na_4Cl solution was obtained (Meiwes et al., 1984). Phosphorus (P) was extracted by the Bray P-1 test (0.03N NH_4F with 0.025N HCl; Olsen and Sommers, 1982) and measured with an UV–vis spectrometer (UV-1800, Shimadzu) at 973 nm after molybdenum blue reaction. Grain size distribution was determined by a combined sieving-sedimentation process according to DIN ISO 11277 (NAW, 2002). Grain sizes were classified according to Ad-hoc-AG Boden (2005).

Table 3
Number and location of replicates of the compared agrosystems.

	AF	CS	TS
No. of sampled fields	8 fields at the only AF farm (no. 1) in the study area	8 fields at 4 farms (no. 5–8)	8 fields at 5 farms (no. 2–6)
Total no. of field samples	16	16	16
Total no. of terrace riser samples	16	15	16

2.4. Statistical analysis

The three agrosystems' mean values of soil parameters were tested for significant differences by ANOVA (normally distributed values) and *H*-test (non-normally distributed values). Multiple comparisons led to the determination of significant differences. We used for computations the packages pgirmess (Giraudoux, 2012), multcomp (Hothorn et al., 2008), and agricolae (de Mendiburu, 2012), and for the construction of boxplots a modified code of the package gplots (Warnes et al., 2012) in the free statistical software environment R (version 2.15.1; R Development Core Team, 2012).

3. Results

3.1. General soil characteristics

In general, the reference profiles of terrace fields show weakly developed horizons (Ah–Bw–C) due to perturbations in the course of anthropogenic terracing processes. Relevant properties of all studied soils are summarized in the left sections of Figs. 2–9 and in Table 4. The sand fraction dominates the grain size distribution of all analysed soil samples (mostly sandy loam), with no significant differences between the three agrosystems (cf. Table 4). We identified a remarkable high content of biotite in most samples. We measured low pH values (between pH 3.85 and pH 5.71) indicating advanced acidification. Corresponding to the low pH values and the HCl test's results, the soils are free of carbonate. Electric conductivity ranges from very low (0.17 mS/cm) to high values (5.38 mS/cm). Organic matter content of the samples varies between very low (<0.004%) and medium (3.43%), suggesting a moderate accumulation of organic matter. Similarly, N_t concentrations vary between low (0.01%) and high (0.21%) values, with a medium mean value (0.10%). The soil's CEC is very low, between 1.5 and 6.5 $cmol_c$/kg. Base saturation varies over a wide spectrum (17.12–99.0%), the mean of all agrosystems, however, is above 50% and thus classified as 'high'. Soil P content again shows a wide range with a large portion of rather low values below 50 mg/kg.

3.2. Comparison of AF, CS, and TS soil properties

pH ($CaCl_2$), aluminium (Al^{3+}) and iron (Fe^{3+}): We found a significant difference between the pH of the AF field soils (median pH 4.83) and the CS field soils (median pH 4.30, Fig. 2). All AF field samples can be assigned to the silicate exchanger buffer (pH 6.2–4.2); none of the AF samples is within the aluminium buffer range below pH 4.2. Conversely, half of the CS samples can be attributed to the aluminium buffer range, but none of them to the iron buffer range ($pH < 3.2$) (Schulze and Ulrich, 1991). In consequence, Al^{3+} and Fe^{3+} contents of the AF field soils are very low: all AF samples contain less than 0.32 $cmol_c$/kg Al^{3+} while the CS field soils' median is 1.02 $cmol_c$/kg Al^{3+} (Fig. 3 and Table 4). The AF samples' average iron content shows 8.58 μmol_c/kg Fe^{3+} while it is 43.08 μmol_c/kg Fe^{3+} in the CS, with high standard deviations (Table 4). The terrace riser soils exhibit low pH values of c. pH 4.5 and medium Al^{3+} values of 0.77 $cmol_c$/kg (AF), 0.82 $cmol_c$/kg

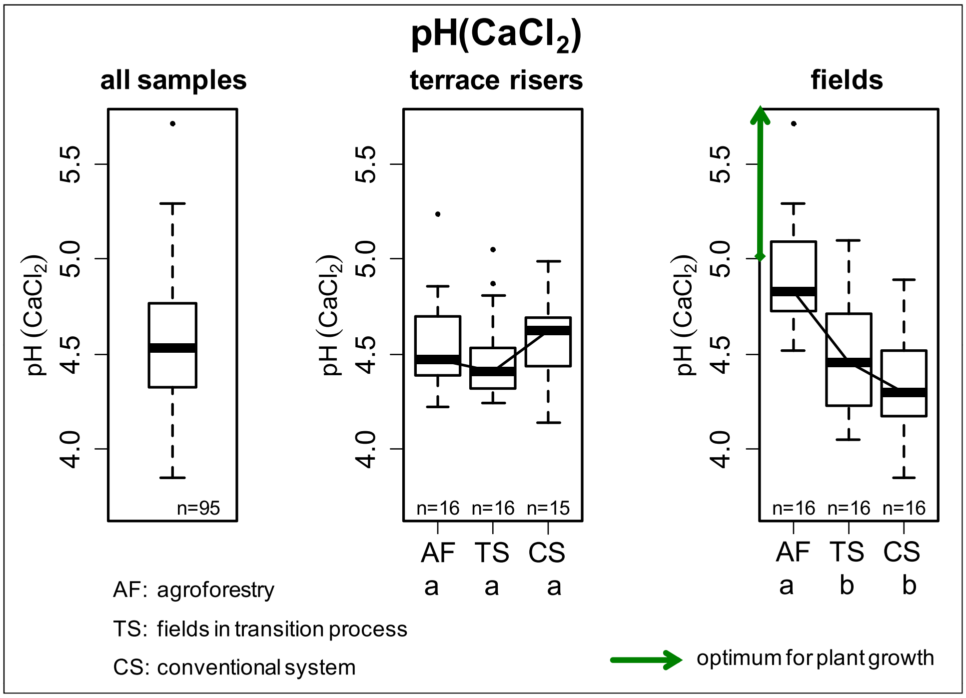

Fig. 2. Value distribution of pH for all samples (left), terrace risers (middle) and fields (right). Boxes with different letters at each box are significantly different at $p < 0.05$. Optimum for plant growth: pH 5–7 (Brady and Weil, 2014).

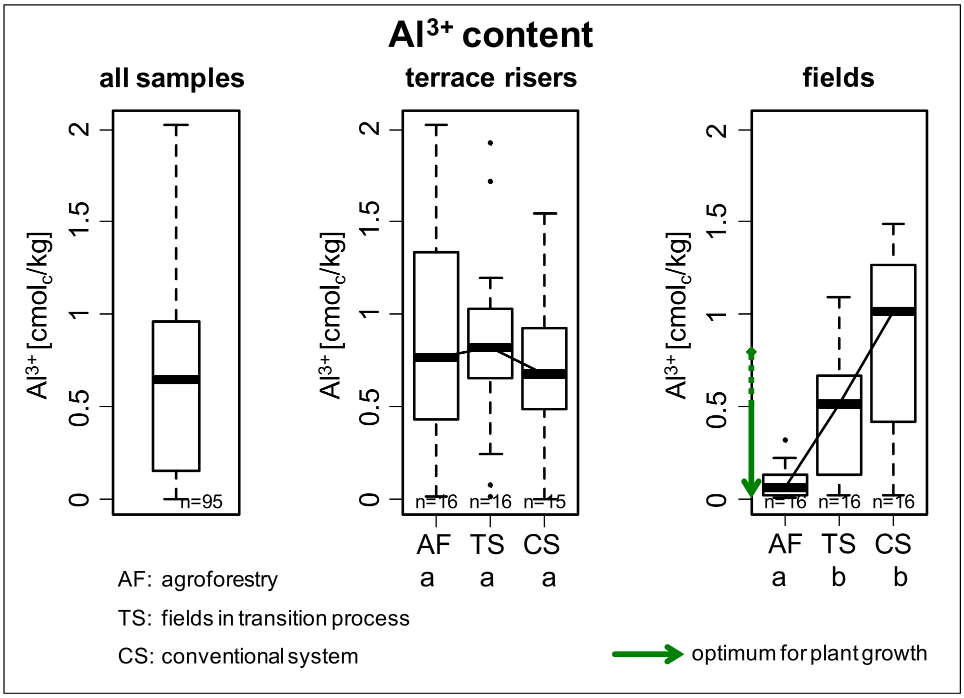

Fig. 3. Value distribution of Al^{3+} content for all samples (left), terrace risers (middle) and fields (right). Boxes with different letters at each box are significantly different at $p < 0.05$. Optimum values for plant growth: $Al^{3+}/KAK < 0.3$ (Landon, 1991), $pH_{CaCl} > 4.8$ (Brady and Weil, 2014).

(TS), and 0.67 $cmol_c/kg$ (CS), respectively. The terrace riser soils do not show significant differences in both pH and Al^{3+} content across the agrosystems AF, CS, and TS while the field soils differ significantly between AF and CS. The Al^{3+} content of the TS field soils does not differ significantly from the CS; however, a trend towards the AF values is obvious.

Base saturation (BS): The soils of the AF and CS fields differ significantly in terms of BS. The BS range of the AF soils is small, reaching from 86% to 99% (median 97%), while the CS soils show a wide spectrum of BS values from 34% to 98% (median 67%; Fig. 4). The median BS of the TS field soils (76%) is somewhat higher and shows a slight and insignificant trend towards the AF

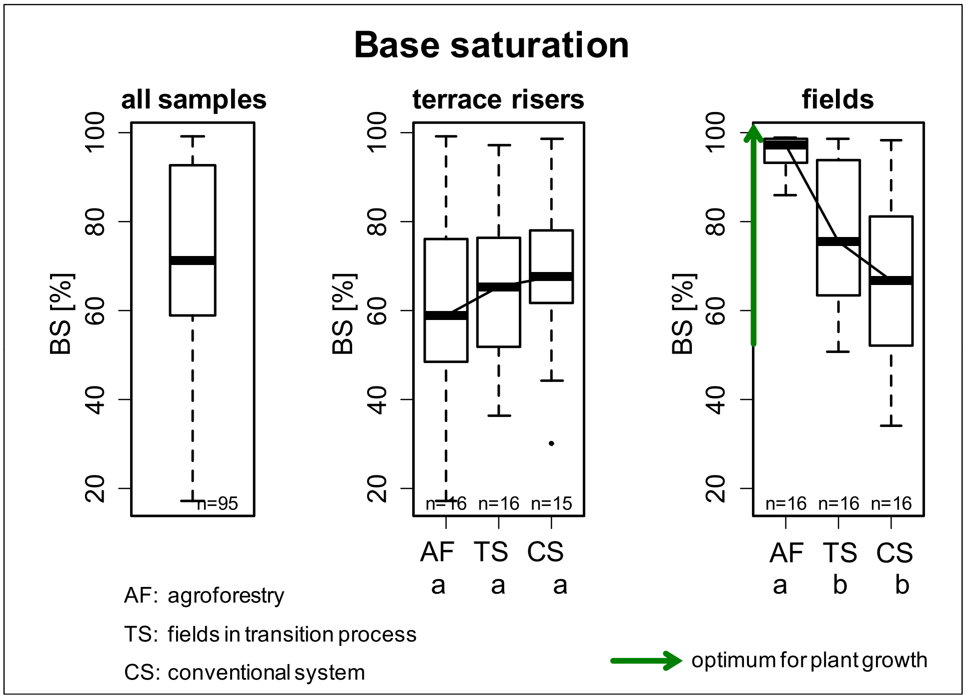

Fig. 4. Value distribution of BS for all samples (left), terrace risers (middle) and fields (right). Boxes with different letters at each box are significantly different at $p < 0.05$. Optimum for plant growth above 50% (Landon, 1991).

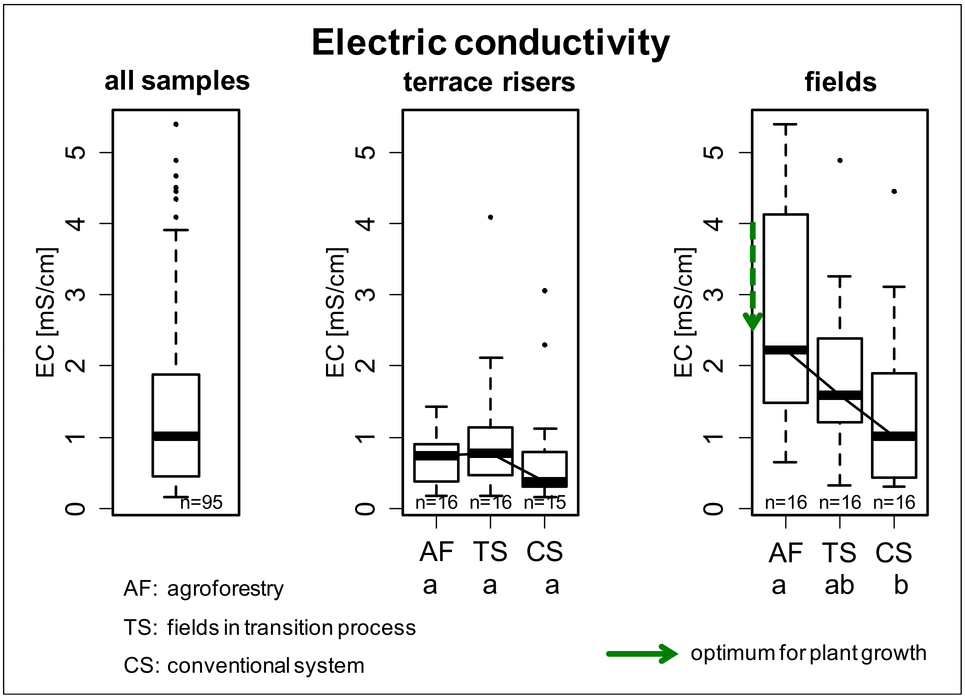

Fig. 5. Value distribution of EC for all samples (left), terrace risers (middle) and fields (right). Boxes with different letters at each box are significantly different at $p < 0.05$. Optimum for plant growth below 4 μS/cm (Landon, 1991).

median. By contrast, base saturation values of the terrace risers soils of all three systems vary over a wide spectrum. The medians are 59% (AF), 65% (TS) and 68% (CS). The risers' soils did not show significant differences in BS between the systems.

Electric conductivity (EC): As for EC, the field soils exhibit a significant difference between the values of AF (median 2.23 mS/cm) and CS (median 1.02 mS/cm; Fig. 5). We found a notably wide range of EC values in the AF soils, from 0.65 mS/cm up to 5.38 mS/cm. The EC of the TS soils does not differ significantly from those of the CS; however, a slight trend towards the respective AF values is visible. None of the three systems' median EC values of the terrace riser soils exceeds 1 mS/cm, and there is no distinct difference between the systems.

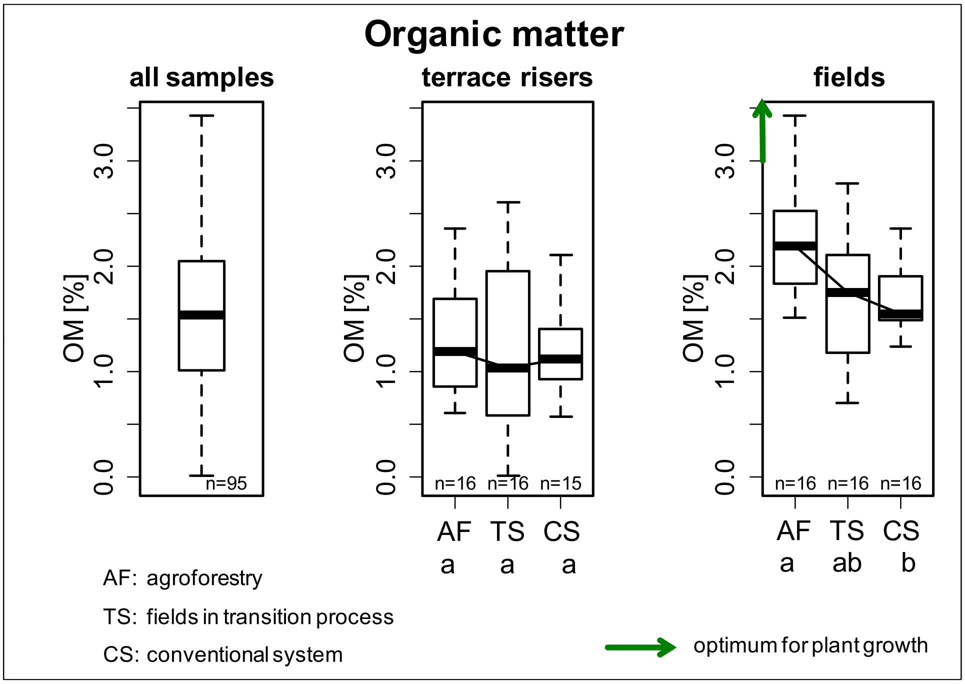

Fig. 6. Value distribution of OM content for all samples (left), terrace risers (middle) and fields (right). Boxes with different letters at each box are significantly different at $p < 0.05$. Optimum for plant growth above 3–8% and higher (Miller and Donahue, 1990).

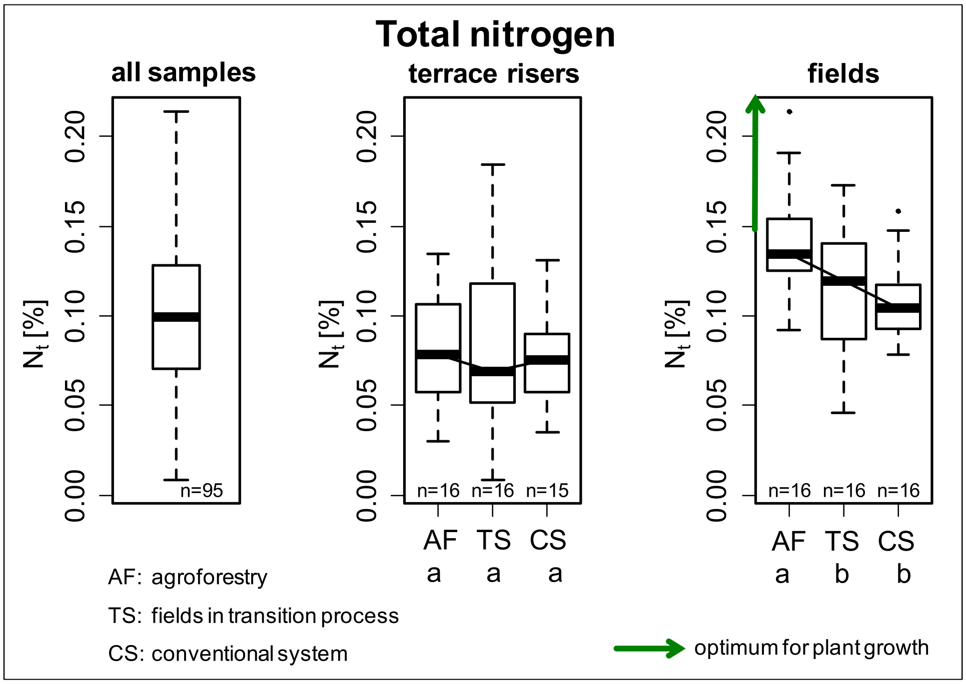

Fig. 7. Value distribution of N_t content for all samples (left), terrace risers (middle) and fields (right). Boxes with different letters at each box are significantly different at $p < 0.05$. Optimum for plant growth above 0.15–0.2% (Brady and Weil, 2014; Landon, 1991).

Organic matter(OM) contents of the three systems' field soils show significant differences. The median of the AF field soils is 2.19%, values range from 1.51% up to 3.43%. OM content of the CS soils is lower compared to the AF; the CS median is 1.55% with a range up to 2.36% and down to 1.24%. The organic matter content of the TS soils is intermediate between the two other systems. In contrast to the field soils, the organic matter content of the three systems' terrace riser soils does not vary much, the medians are 1.09% (AF), 1.03% (TS), and 1.12% (CS), respectively.

Total Nitrogen – N_t: As for total nitrogen, we found a significant difference between the AF field soils (0.13%) and the CS field soils (0.10%; Fig. 7). AF field soils attain highest N_t contents; their

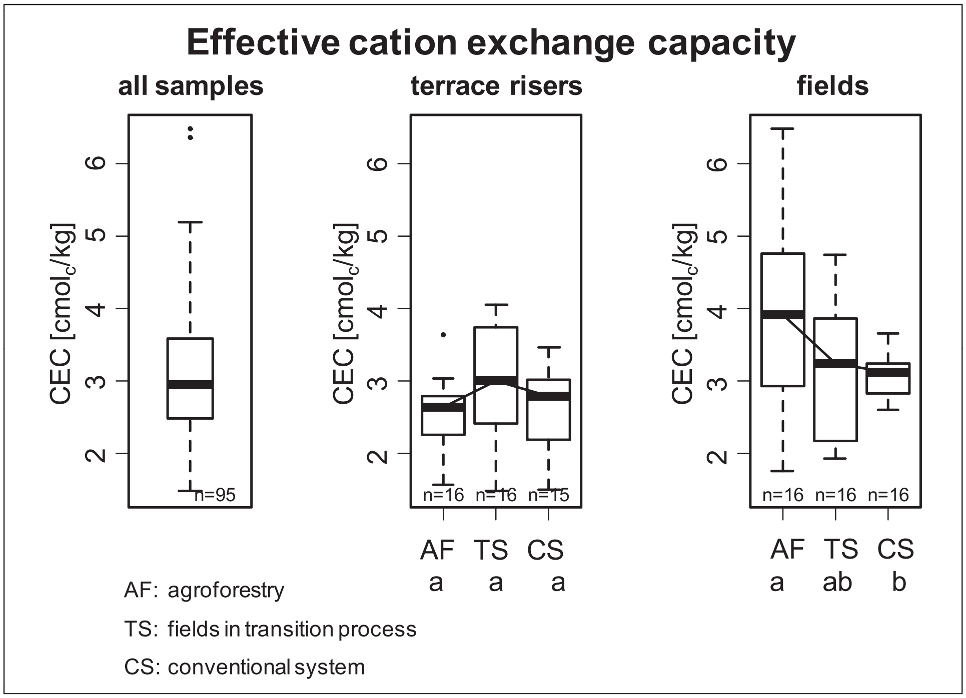

Fig. 8. Value distribution of CEC for all samples (left), terrace risers (middle) and fields (right). Boxes with different letters at each box are significantly different at $p < 0.05$. Optimum for plant growth above 8–10 cmol_c/kg, below 4 cmol_c/kg unsuitable for irrigated agriculture (Landon, 1991).

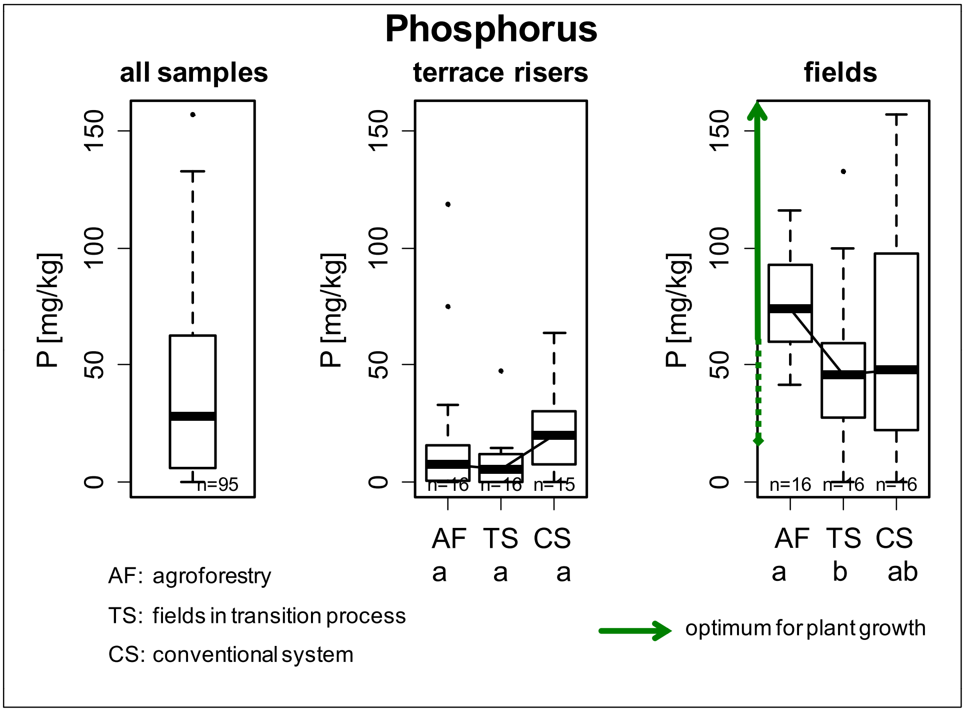

Fig. 9. Value distribution of P content for all samples (left), terrace risers (middle) and fields (right). Boxes with different letters at each box are significantly different at $p < 0.05$. Optimum for plant growth above 15–60 mg/kg (Kovar and Pierzynski, 2009; Pagel et al., 1982; von Westarp et al., 2004).

maximum value is 0.21% while we found the lowest N_t content in a sample of the TS (0.05%). We could not identify for N_t any trend of the TS field soils towards those of the AF field soils: The CS and TS medians do not vary much (CS: 0.10%, TS: 0.12%), and in addition the minimum and first quartile of the TS range lowest across all systems. By contrast, total nitrogen content of the terrace riser soils does not exhibit any significant difference between the compared agrosystems. Median values are low, with 0.08% for the AF and CS systems, and 0.07% for the TS system.

Effective cation exchange capacity (CEC): The field soils exhibit a significant difference between the CEC of the AF and the CS system, with the AF system showing a much higher median value (AF: 3.9 $cmol_c$/kg, TS: 3.2 $cmol_c$/kg, CS: 3.1 $cmol_c$/kg; Fig. 8). There is a remarkably wide range of the AF soils' CEC, with the maximum at 6.5 $cmol_c$/kg and the minimum at 1.8 $cmol_c$/kg, and a rather small range of the CS soils' CEC (max.: 3.7 $cmol_c$/kg; min.: 2.6 $cmol_c$/kg). We found a wider range of the TS values in comparison to the CS soils, but the TS soils' median (3.2 $cmol_c$/kg) stands close to the CS soils' median. Concerning the values' ranges, the TS soils rather resemble the AF soils. Compared to the field soils, the terrace riser soils show only slight differences in terms of effective cation exchange capacity. Median values are 2.6 $cmol_c$/kg (AF), 3.0 $cmol_c$/kg (TS), and 2.8 $cmol_c$/kg (CS), respectively.

Phosphorus (P): The median values of the phosphorus content (Bray P-1 test) of the field soils are 73.8 mg/kg (AF), 46.1 mg/kg (TS), and 48.2 mg/kg (CS), respectively (Fig. 9). Although the median of the AF soils is far higher compared to the TS and CS soils, the differences are not significant at the 0.05 level due to the wide ranges, especially in case of the CS and the TS soils. The range of the CS field soils is widest, from the limit of quantification to a P content of 156.5 mg/kg, while the maximum P content found in the TS soils reaches 132.5 mg/kg. The AF field soils show the smallest P content range across the systems with a minimum value of 41.5 mg/kg, indicating the comparatively most balanced P supply. The P content is distinctly higher in the field soils in comparison to the terrace riser soils: Their phosphorus content is extremely low, with some notable exceptions. The median values account for 7.7 mg/kg (AF), 5.6 mg/kg (TS), and 19.9 mg/kg (CS), respectively. There are no significant differences to detect across the compared systems.

Overview of compared soil physical and chemical parameters: Summing up the results of the soil analyses (cf. Table 4), significant differences between the AF and CS field soils could be detected by ANOVA and Kruskal–Wallis tests for all tested parameters except for phosphorus and Mn^{2+} contents and grain size. Parameters include the exchangeable cations Na^+, Ca^{2+}, Fe^{3+}, Mg^{2+}, K^+. Soil parameters of AF fields are distinctly more favourable to plant growth than those of the CS fields, although measured data are often below the level recommended for crop cultivation in respective textbooks (cf. Brady and Weil, 2014; Landon, 1991; see Section 4.2). For several parameters, TS field soils show a convergence trend in their values towards AF soils. In contrast to the terrace fields, the corresponding terrace risers do not exhibit any significant differences between the agrosystems.

4. Discussion

4.1. General soil characteristics

Results pertaining to general soil characteristics are in good accordance with those of other studies from the mid-hills of Nepal. Our findings concerning the high biotite content correspond to the petrographic study of Peters and Mool (1983), who assigned the bedrock of Kaule area to two-mica gneisses series belonging tectonically to the Kathmandu complex which comprises a stratigraphic sequence ranging from late-Precambrian to Ordovician. The assessed low soil pH, to be attributed to the monsoonal climate and the acidic gneissic bedrock, is in accordance with other soil pH analyses from the mid-hills of Nepal (e.g. Carson, 1992; Carson et al., 1986; Desbiez et al., 2004; von Westarp et al., 2004). Values of BS range from 10% to 100% in Nepal (Carson et al., 1986). Other studies of mid-hill soils reported BS values similar to the

Table 4
Descriptive statistics of soil analyses results for all plots (all), and samples of AF, TS, and CS fields and terrace risers. <DL: below detection limit.

	pH ($CaCl_2$)	EC (mS/cm)	C_t (%)	OM (%)	N_t (%)	CEC ($cmol_c$/kg)	BS (%)	Al^{3+} ($cmol_c$/kg)	Na^+ ($cmol_c$/kg)	Ca^{2+} ($cmol_c$/kg)	Fe^{3+} (μmol_c/kg)	Mg^{2+} ($cmol_c$/kg)	Mn^{2+} ($cmol_c$/kg)	K^+ ($cmol_c$/kg)	P (mg/kg)	Sand (%)	Silt (%)	Clay (%)
All plots																		
Min all	3.85	0.17	<DL	<DL	0.01	1.49	17.12	<DL	<DL	0.29	<DL	0.08	0.01	<DL	<DL	29.13	15.47	4.19
Mean all	**4.57**	**1.41**	**0.92**	**1.58**	**0.10**	**3.07**	**72.72**	**0.632**	**0.03**	**1.74**	**13.12**	**0.40**	**0.04**	**0.16**	**39.26**	**63.81**	**23.81**	**12.37**
Max all	5.71	5.38	1.99	3.43	0.21	6.47	99.00	2.022	0.39	4.94	190.70	0.98	0.10	0.50	156.50	79.94	36.84	35.30
SD all	0.32	1.24	0.39	0.67	0.04	0.94	20.39	0.512	0.05	0.98	30.43	0.20	0.02	0.10	38.14	9.73	4.44	5.99
Fields																		
Min AF	4.52	0.65	0.88	1.51	0.09	1.77	85.92	0.003	<DL	1.38	<DL	0.23	0.03	0.05	41.52	59.78	15.47	4.95
Mean AF	**4.92**	**2.63**	**1.33**	**2.28**	**0.14**	**4.04**	**95.66**	**0.090**	**0.02**	**3.02**	**8.58**	**0.62**	**0.05**	**0.23**	**75.89**	**70.00**	**20.41**	**9.59**
Max AF	5.71	5.38	1.99	3.43	0.21	6.47	98.85	0.319	0.07	4.94	80.17	0.98	0.07	0.41	115.90	77.51	25.22	15.00
SD AF	0.32	1.52	0.34	0.58	0.03	1.28	3.89	0.091	0.02	1.03	20.39	0.22	0.01	0.11	21.92	4.48	2.51	2.93
Min TS	4.05	0.32	0.41	0.71	0.05	1.94	50.75	0.018	<DL	0.79	<DL	0.14	0.03	0.03	<DL	40.77	16.38	5.24
Mean TS	**4.50**	**1.90**	**1.01**	**1.74**	**0.11**	**3.13**	**77.68**	**0.454**	**0.02**	**1.91**	**3.30**	**0.46**	**0.06**	**0.15**	**49.13**	**65.78**	**23.42**	**10.80**
Max TS	5.10	4.89	1.62	2.78	0.17	4.75	98.66	1.091	0.08	3.57	33.14	0.75	0.10	0.26	132.50	77.94	31.89	27.34
SD TS	0.30	1.14	0.36	0.62	0.04	0.94	16.38	0.352	0.03	0.95	8.43	0.20	0.02	0.08	32.90	9.18	3.57	6.07
Min CS	3.85	0.31	0.72	1.24	0.08	2.61	34.11	0.019	<DL	0.66	<DL	0.16	0.03	0.07	<DL	41.20	19.55	7.08
Mean CS	**4.36**	**1.38**	**1.00**	**1.71**	**0.11**	**3.10**	**67.05**	**0.869**	**0.05**	**1.52**	**43.08**	**0.38**	**0.05**	**0.16**	**59.97**	**60.72**	**25.38**	**13.90**
Max CS	4.89	4.44	1.37	2.36	0.16	3.65	98.19	1.492	0.12	2.64	190.70	0.56	0.06	0.25	156.50	72.18	36.84	24.04
SD CS	0.28	1.15	0.21	0.36	0.02	0.32	18.55	0.487	0.03	0.56	61.51	0.12	0.01	0.05	47.34	8.30	4.79	4.75
Terrace risers																		
Min AF	4.22	0.18	0.36	0.61	0.03	1.57	17.12	0.015	<DL	0.34	<DL	0.08	0.01	<DL	<DL	45.22	15.87	4.19
Mean AF	**4.54**	**0.72**	**0.75**	**1.28**	**0.08**	**2.52**	**60.25**	**0.884**	**0.01**	**1.11**	**5.79**	**0.28**	**0.03**	**0.14**	**19.29**	**64.76**	**22.71**	**12.53**
Max AF	5.24	1.44	1.37	2.36	0.13	3.64	99.00	2.022	0.04	2.81	24.10	0.63	0.08	0.50	118.70	79.94	32.27	26.59
SD AF	0.27	0.40	0.30	0.51	0.03	0.55	22.03	0.576	0.01	0.61	6.91	0.15	0.02	0.12	32.48	10.53	4.41	6.69
Min TS	4.24	0.18	<DL	<DL	0.01	1.49	36.40	0.016	<DL	0.46	<DL	0.08	0.02	<DL	<DL	29.13	17.56	4.57
Mean TS	**4.49**	**1.05**	**0.71**	**1.21**	**0.08**	**2.96**	**66.08**	**0.833**	**0.05**	**1.48**	**5.79**	**0.35**	**0.04**	**0.14**	**8.26**	**59.50**	**26.08**	**14.42**
Max TS	5.05	4.09	1.52	2.61	0.18	4.05	97.29	1.926	0.39	2.79	27.55	0.66	0.07	0.37	47.81	75.51	35.56	35.30
SD TS	0.23	0.95	0.44	0.75	0.05	0.84	17.99	0.511	0.10	0.72	8.55	0.17	0.02	0.11	11.92	13.75	5.41	8.85
Min CS	4.14	0.17	0.33	0.57	0.04	1.51	30.11	<DL	<DL	0.29	<DL	0.08	0.01	0.02	<DL	48.17	20.89	6.93
Mean CS	**4.58**	**0.75**	**0.70**	**1.20**	**0.08**	**2.62**	**69.38**	**0.666**	**0.04**	**1.39**	**12.15**	**0.32**	**0.02**	**0.13**	**21.97**	**62.01**	**24.95**	**13.04**
Max CS	4.99	3.05	1.23	2.11	0.13	3.47	98.68	1.545	0.10	2.73	59.89	0.53	0.06	0.25	63.57	72.18	33.48	18.50
SD CS	0.23	0.84	0.23	0.39	0.03	0.60	18.60	0.417	0.03	0.66	15.16	0.13	0.01	0.08	19.99	6.64	3.22	4.03

range of values we measured (Schreier et al., 1999; Shrestha, 2009; von Westarp et al., 2004), however, the median value of our analyses is slightly higher than in the reference studies. The average OM content of the analysed soils is comparable to other results from the mid-hill region of Nepal. Neupane and Thapa (2001) found an OM content of 1.5–2.3%, Desbiez et al. (2004) reported 2–3%, and Carson (1992) assessed 0.5–3% with an average under 1%. The mean value of all samples (1.6%) is higher in our results, caused by the higher OM content of the AF system. The N_t content that we found (0.01–0.21%) corresponds roughly to other results from the mid-hills of Nepal (0.05–0.12%, Neupane and Thapa, 2001; 0.15–0.10%, Desbiez et al., 2004; 0.09–0.13%, Shrestha 2009). In general, nitrogen levels in farmers' fields in Nepal show deficiencies compared to other agricultural regions (Carson, 1992). This case study corroborates this statement. The CEC values of the present study are consistent with the results of Shrestha (2009). Other studies from the Nepalese mid-hills reported CEC values above 10 $cmol_c$/kg (Carson et al., 1986; Kollmair, 1999; Schreier et al., 2006), however, these values are not well comparable due to differing analytical methods. The comparatively low CEC values found in the samples from Kaule can be attributed to strong leaching during the annual rainy season, and to low soil pH. Moreover, the soils' clay content is low, and we suppose a dominance of kaolinitic clay because of highly weathered minerals, as Shrestha (2009) did for another study site in the mid-hill region. Phosphorus contents of mid-hill soils are provided by von Westarp et al. (2004) and Acharya et al. (2007), who report values that correspond to the P levels we found in the terrace field soils. The values of the field soils often range below the desirable levels for optimum plant growth – a general feature of the mid-hill soils as the cited reference studies show. The underlying interrelationships of pedogenetic factors, e.g. bedrock, high precipitation causing eluvial processes, and intensive land use obviously inhibit the development of more fertile soils. Respective values of the terrace riser soils (cf. Table 4) are by far below the values given in the reference studies, proving their suitability as unmanaged controls. The terrace field soils exhibit wide ranges of P content – a phenomenon that might be attributed to uneven application of fertilizer. In summary, all values of the soils of this study are more or less consistent with results of reference studies in the mid-hill region. Thus, they can be considered characteristic for soils of the mid-hills of Nepal, provided typical soils exist as a considerable small-scale variability of soil properties has to be assumed on any mountain slope in Nepal (Carson, 1992).

4.2. Contrasting soil quality of agrosystems

Significant differences between AF and CS in all analysed chemical soil parameters except P and Mn^{2+} contents indicate a higher soil quality and more fertile soil conditions in the AF field soils. Minimized differences in soil conditions potentially aroused by abiotic or biotic determinants not directly related to the cultivation practice and the fact that terrace riser soils serving as unmanaged controls do not exhibit significant differences between systems suggest that contrasting soil quality has to be largely attributed to differing land management practices. Specific agrosystems such as AF and CS induce specific ranges of soil properties. Within these ranges, complex interactions of single soil parameters result in a certain degree of variability of soil characteristics, with pH level and OM content playing major driving roles.

Many soil parameters are influenced by the prevalent acidity of the soils, which, apart from steep slopes causing soil erosion

(Gardner and Gerrard, 2003) seems to be the biggest challenge for agriculture in Kaule and probably the mid-hills in general (e.g. Atreya et al., 2006; Schreier et al., 2001; von Westarp et al., 2004). Liming could be a suitable measure to stabilize and raise pH and lower Al^{3+} content, given that lime is available at a reasonable price and that it is possible to integrate the application into the crop rotation. Since free aluminium cations adversely affect plant growth (e.g. Brady and Weil, 2014; Fageria, 2012), farmers usually tend to attain higher soil pH values. In general, farmers apply lime to acidic soils, which is not the case in Kaule, probably due to limited availability and financial constraints. The AF farmer in Kaule succeeded to raise soil pH significantly on his fields without liming, obviously by rejecting mineral fertilizer and use of organic fertilizer instead. The application of mineral N fertilizer followed by nitrification processes often causes severe acidification (Brady and Weil, 2014; Carson, 1992; Shrestha, 2009; Zhu et al., 2011), while traditionally high rates of organic matter additions through compost are used to prevent acidification (Carson, 1992). Humus is an important buffer, reducing fluctuations in soil acidity (Bot and Benites, 2005; Brady and Weil, 2014).

The antagonistic relationship of BS and Al^{3+} content (cf. Figs. 3 and 4) has to be discussed in the light of prevailing soil acidity. Soils with less than 50% BS are regarded as inherently less fertile (Carson et al., 1986). All AF samples' BS exceed 80% and are in the 'optimal' range (Kuntze et al., 1994) – a major difference compared to other agricultural sites in Nepal (e.g. Schreier et al., 1999; von Westarp et al., 2004). However, the lower BS values of CS and TS are consistent with the above cited reference studies, and indicate the replacement of macronutrient cations by acidifying cations (H^+, Fe^{3+}, and Al^{3+}). In AF soils, this process is obviously partially inhibited by higher OM content (see below; Fageria, 2012), even though strong leaching during the monsoon season leads to base eluviation.

Sufficient humidity and relatively high temperatures in the mid-hills favour microbiological activity in the soil and rapid decomposition (Bot and Benites, 2005; Kollmair, 1999), leading to low OM content in some of the sampled soils, especially in CS soils. By contrast, the majority of the AF OM values can be classified as having 'medium' humus content or more (cf. Ad-hoc-AG Boden, 2005). The average OM content of the AF tends to the recommended range which starts at 3% OM content (Miller and Donahue, 1990). The input of OM from lopped or natural fallen litter and plant material metabolised by cattle plays an important role in nutrient supply of AF systems. Moreover, the OM content is crucial in achieving more fertile conditions by enhancing the soil's capacity for storing water and available macro- and micro-nutrients, and by reducing susceptibility to erosion. Agricultural soils with high OM and thereby high C content can function as carbon sinks. In Kaule and the mid-hill region in general, the ability of OM to positively influence soil water budget can play a vital role in increasing the yield of off-season vegetables during the annual dry season (Bot and Benites, 2005; Fageria, 2012; Thorne and Tanner, 2002; Young, 1997). Higher OM content in AF soils might also provide an enhanced control of phytophagous pests by facilitating antagonists (cf. Fageria, 2012; Martin and Sauerborn, 2013). OM combined with farmyard manure is able to sequester Al^{3+} complexly, block the toxic effect and support plant growth despite low pH (Fageria, 2012). Both OM and farmyard manure is applied in higher quantity on AF fields than on CS and TS fields. Corresponding to OM, Al^{3+}, and BS analyses, we observed higher input of organic materials in the AF system in terms of green and farmyard manure, composted crop residues and kitchen waste, and organic matter from the farmer's fish pond (algae). Significantly higher OM content of the AF soils (cf. Fig. 6) most likely favours plant growth and yield in this system in which green manure and farmyard manure are usually applied to raise the OM content. In order to use the manure input more efficiently, farmers in Kaule could improve its application: they often stack farmyard manure and expose it to weather conditions before incorporating it into the soil to reduce the termite and ant problem, but causing eluviations, oxidation and volatilization of considerable amounts of nutrients. More effective storage and composting techniques could reduce these losses (Bista et al., 2010; Carson, 1992; Shrestha, 2009) and contribute to a more successful transition to AF. In contrast to the use of OM, the intensified use of mineral fertilizers in the CS enhances acidification and deteriorates the quality of surface and ground water, especially downstream (Brady and Weil, 2014; Dahal et al., 2007; Galloway et al., 2008; Pierzynski et al., 2005). This practice may have consequences beyond the local and regional scale (Gruber and Galloway, 2008; Rice and Herman, 2012). In Kaule, mineral fertilizers are mainly applied in the CS in the context of strawberry cultivation (Bista et al., 2010), which as a monocropping system adversely affects soil properties and biodiversity.

The AF field samples show the highest EC of the compared systems, some AF values reach maximum values above 4 ms/cm (saturation extract), a range where crops may suffer damage from salinization (Landon, 1991). High EC values are most often caused by inappropriate irrigation practices or by the input of both mineral and organic fertilizer (Eghball, 2002; Eghball et al., 2004; Miller et al., 2005). However, in this case the risk of salinization is relatively low due to the effects of monsoon precipitation and sandy soil texture. The intensity of irrigation is estimated to be lower in the AF system compared to the CS. In conclusion, the significantly higher EC of the AF fields most likely originates from more intense fertilization, in this case from organic fertilizer solely.

Significantly higher N_t of AF field soils compared to CS and TS soils must be attributed to higher OM content and the comparatively excessive cultivation of legume species (Fabaceae) in the AF system (see also Lamichhane, 2013), in terms of both species richness and number of individuals. However, even the AF N_t mean value reaches just the optimum nutrition for plant growth (Brady and Weil, 2014; Landon, 1991). In general, low soil pH inhibits the N mineralization process, resulting in a rather small percentage of plant available N_t. In our case study, further analyses are needed to quantify the single N-fractions. N_t accumulates in cultivated soils only in the long term (Scheffer et al., 2010). Accordingly, only less pronounced differences in N_t between the agrosystems were found compared to other analyzed soil parameters. The few elevated N_t values of CS samples reflect a 3–4 times higher input of mineral N fertilizer in the strawberry fields of CS compared to the wheat, maize and paddy fields of the same system (cf. Bista et al., 2010).

As a measure for soil fertility and nutrient content, CEC depends mainly on the percentage of clay minerals and humified organic matter. CEC of nearly all analyzed field samples is less than 5 $cmol_c$/kg and can be classified as 'very low' according to Landon (1991). Nevertheless, the significantly higher CEC of AF soils compared to CS soils implies more fertile conditions. Because soil texture and clay content do not differ between the agrosystems, but the OM content does, we conclude that the differences in CEC must be attributed to the differing OM content. Higher OM content is obviously caused by the AF management (see above) which in consequence induces a higher CEC and thereby more favourable soil conditions for plant growth in the AF soils.

Since only a small part of the phosphorus fraction is available to plants directly and a high amount of P is exported out of the system by harvesting crops, phosphorus is a limiting factor for plant growth (Pierzynski et al., 2005). Assuming that a soil P content of c. 40 mg/kg (Bray P-1 test) represents a minimum target value (ranging from 15 to 60 mg/kg according to Kovar and Pierzynski, 2009; Pagel et al., 1982; von Westarp et al., 2004), only about half of the CS and TS field soils show sufficient P content (some with rather high content though), while nearly all AF values exceed this threshold. In contrast to nitrogen fixation by legume species, phosphorus cannot be ‘produced’ locally at the farms. With increasing soil nitrogen content and higher yields, the P export increases and P can become a deficient element (Carson, 1992). Schreier et al. (2001) identified significant P deficits in maize production systems, and to a lesser extent in rice cropping systems in the mid-hills of Nepal. Like nitrogen, Nepal needs to import P, in consequence availability of P fertilizer is limited and purchase costly. Farms in Kaule, except the AF farm, use rapidly dissolving diammonium phosphate (DAP) on certain fields, e.g. on strawberry fields, to compensate the P export (pers. comm.). The uneven input of P fertilizer might be the reason for the wide ranges of P content in TS and especially CS soils. Due to this wide spectrum, the P content of AF soils does not significantly differ from the other systems. However, extremely low P values do not occur in AF samples. The AF farmer reaches a more even and adequate P content without mineral DAP fertilizer input. Apart from P mineral fertilizer, compost, animal manure and other organic matter can contribute directly to P supply, even though to a lesser extent than to nitrogen supply, and indirectly as well by creating a higher P sorption capacity of the soil (Carson, 1992; Pierzynski et al., 2005; Schreier et al., 1999).

Soil parameters of **terrace riser** samples do not differ significantly across the agrosystems. Potential differences that may arise from factors independent from land management, e.g. small-scale differing bedrocks or other varying environmental factors, could not be detected. Thus, the terrace riser samples, taken in immediate vicinity to the sampled fields, can be used as uncultivated controlss. They show similar median values in all systems, corroborating the assumption that differences in soil conditions are almost exclusively induced by deviating management practices. At the same time terrace riser samples indicate clearly less suitable conditions for plant growth compared to the fields' samples. This is valid for all above discussed parameters.

Summing up, all results of chemical parameters, except P and Mn^{2+}, indicate significantly more favourable conditions for plant growth in AF fields compared to CS fields, obviously triggered by higher investment in organic manure, improved compost composition and higher abundance of nitrogen fixing trees (cf. Tables 1 and 2). Many TS soils show a trend towards AF values, indicating a distinct influence of the improved management on soil properties after 2 years only. By comparing the variation between field samples and samples from unmanaged terrace risers, the impact of different cultivation practices becomes evident.

5. Conclusions

The results of the present study and related research endeavours clearly show that agroforestry systems have the potential to significantly enhance soil quality, in particular in terms of sustainable nutrient security and long-term soil productivity. Distinct differences in cultivation practices between the AF farm and the CS farms in Kaule have resulted in significantly deviating soil properties. The AF soil provides distinctly more favourable growth conditions in terms of soil chemical parameters after 15 years of AF management. And after two years only, the majority of tested parameters of TS soils already shows a tendency towards improved fertility. The reorientation to agroforestry practices in Kaule village has considerably contributed to natural resource sustainability. The adoption of agroforestry practices most likely involves the provision of other ecosystems services and environmental benefits such as reduced soil erosion, carbon sequestration, improved air and water quality, enhanced biodiversity, and increased landscape aesthetics. Enhancing and maintaining land productivity will enable local farmers to sustain their farms, improve their crop yields, diversify their income sources, and improve the economic conditions of households. We propose to further promote improved agroforestry practices and stimulate interest in other villages in the mid-hills of Nepal and elsewhere.

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