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Biophysical criteria used by farmers for fallow selection in West and Central Africa

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ABSTRACT

In many parts of the humid Tropics, slash and burn shifting cultivation, incorporating a fallow phase, is the most common farming method, encompassing a broad diversity of techniques. The ecological productivity and sustainability of such systems depend upon the crop:fallow time ratio. Farmers often have biophysical criteria by which to match parcels to cropping systems and decide, for example, when to recultivate a fallow. In this paper, we collate reports of indicators used by farmers to aid in fallow choice from across the agronomic, forestry, ecological, and anthropological literature.

We found 27 examples of farmers using such biophysical indicators. Examples found were from eight countries across West and Central Africa. The literature review showed that farmers rank fallow age usually first, followed by vegetation composition, the presence of indicator plants, and earthworm casts. 53 indicator plant species were identified across the region of which 37 were said to indicate soil fertility, 13 soil infertility and 3 either fertility or infertility, depending on their growth characteristics. The most exhaustive lists of indicator plants were reported from southern Cameroon, the Ashante region of Ghana and south west Nigeria. *Chromolaena odorata* was the most frequently mentioned plant indicator species. The trees *Triplochiton scleroxylon* and *Terminalia superba* and the grass were each mentioned, generally as soil fertility indicators, in three areas. Other species mentioned multiple times were *Aframomum* sp., *Andropogon gayanus*, *Ceiba pentandra*, *Milicia excelsa*, *Triumfetta cordifolia* and *Trema guineensis*.

Farmers in West and Central Africa have identified indicators for selecting which fallow plots to recultivate. Fallow age, vegetation composition, the presence of indicator plants, particularly *C. odorata*, and earthworm casts all have some logical scientific basis and farmers observations are supported by the results of scientific studies. There is a lack of documentation of farmers' knowledge and more studies should be conducted. Such knowledge should form the foundation of any suggested interventions in farming systems in the region and provide information to farmers in communities where such knowledge is not currently applied.

1. Introduction

In many regions of the humid Tropics, slash and burn shifting cultivation is the most common farming method. Farmers clear, burn and crop a small area of forest or bush fallow. After cropping, the land is abandoned to "fallow", the successional vegetation that follows the cropping phase (Ewel, 1986). After a variable fallow length, the crop:fallow cycle is repeated. The productivity and sustainability of this system are assumed to depend upon the crop:fallow time ratio (after Guillemin, 1956). Fallows regenerate soil fertility, act as a weed-, pest- and disease-break, accumulate biomass, provide wood, green manures, forage and other goods and their properties partially determine future crop yields. A given system has an optimum fallow period for production, longer fallow periods are unnecessary, and shorter fallow periods lead to a decline in productivity (Guillemin, 1956; Mertz, 2002).

In parts of the humid forest zone of West and Central Africa, the area in fallow greatly exceeds that under in crop production at any particular time (Hauser and Norgrove, 2013). In southern Cameroon, for example, the area of land in various stages of fallow is 3.58 times greater than that under food crops, including perennial food crops (calculated after Nolte et al., 2001). Thus farmers can choose plots to cultivate, within the general constraints of land tenure laws. There can be conflict between customary and formal law. For example, in Cameroon, formal law limits local access to

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forested land (Sunderlin et al., 2014). Cropped land near villages is usually undisputed, yet areas further away, particularly fallows, are often contested (Russell et al., 2011). Aspects such as household wealth and thus size of land-holding will influence the amount of choice available to farmers (Gleave, 1996). Apart from these and other social and gender-related issues (Grigsby, 2004), criteria used by farmers include travel time to site (Wilkie and Finn, 1988) and other location factors such as proximity to a road (Gleave, 1996) and to the household's other fields (Brown, 2006). Labour availability is also a criterion (Richards, 1986, quoted in Ickowitz, 2006). However, assessments of potential productivity are critical in the process of site selection (Gilruth et al., 1995).

With increasing population mounting the pressure on land resources, there is a need to develop indicators of the restoration of soil fertility in fallow systems. There are few reports in the literature of fallow indicators used by farmers. Steiner (1998) working in Rwanda reported that 30% of farmers used indicator plants in fallows. Styger et al. (2007) described the detailed characterisation of fallows by farmers in the Betsimisaraka region of Madagascar. Tanaka et al. (2007) described the use of plant indicator species used by the Iban of Sarawak to distinguish between suitable and unsuitable sites. Thein and Minn (2007) mentioned which plants indicated fertile soils in Karen swidden systems in Myanmar. Marquardt et al. (2013) documented a range of fallow properties described by farmers in the Peruvian Amazon to distinguish "good" from "bad" fallows. There are few and albeit scattered reports documenting indicators used by farmers in the West and Central African region.

The objectives of our research were to gather information on biophysical indicators used by farmers to decide when to recultivate a field, to verify to what extent they were valid and to make recommendations on their usage. We focused on the humid forest and forest–savannah transition zones of West and Central Africa given that in this region population density and pressure on land is still sufficiently low that fallowing is practised. Farmers have little access to agricultural extension services for advice so often rely on traditional local knowledge, although due to the high ethnic and linguistic complexity of the region (Michalopoulos, 2012), knowledge diffusion may be limited. Compiling indicators from across the region may thus provide useful information to farmers in comparable biogeographic areas.

2. Materials and methods

We conducted a narrative literature review, collating reports of indicators used by farmers to either aid in fallow choice from across the agronomic, forestry, ecological, and anthropological literature, in English or in French. We included journal articles, books, available grey literature sources and online theses within an unlimited timeframe. We restricted our geographical area to the humid forest and moist savannah agroecosystems (*sensu* Jalloh et al., 2012) of West and Central Africa, ranging from Guinea Bissau in the west to the Democratic Republic of Congo (DRC) in the south-east. Major soils in the region include Oxisols, Ultisols, Alfisols, Entisols and Andisols. References comprised those studies where quantitative surveys had been conducted and also those that simply reported qualitative observational data directly from farmers. We excluded any reference that did not state from whom the indicator was obtained and we also only reported indicators used by farmers. Where results from a single study in a single area were reported in multiple articles, we treated them as a single report. We do not report primary data in this study. Botanical nomenclature was verified using TROPICOS of the Missouri Botanical Gardens.

We found 27 examples of reports of farmer use of indicators comprising 19 journal articles, 2 books, 4 theses and 2 grey literature sources of which one originates from the authors (Birang et al., 2003a). Of these, 7 considered only soil indicators and 7 considered only plant indicators; the remaining 13 reports dealt with all possible indicators. In comparing the relative importance of all indicators, we therefore only considered results from the 13 latter remaining reports as inclusion of all ($n = 27$) would have biased the results. Examples found were from eight countries: Sierra Leone, Côte d'Ivoire, Ghana, Benin, Nigeria, Cameroon, the Republic of Congo and the Democratic Republic of Congo (DRC). 54% of reports either conducted interviews with farmers or used an adapted version of a local game 'bao' (Brown, 2006), fully described in Franzel (2001), to obtain information. The number of farmers questioned (n) ranged from 13 to 600 with a median of $n = 91$. The remaining 46% of reports did not specify the methodology used. 75% were from the humid forest zone and 25% from the forest–savannah transitional zone. We discussed findings by comparing them with the results of experimental studies in the region with some being those of the authors.

3. Results

On average, farmers used 2–3 indicators to determine when to recultivate a fallow. Across studies, excluding those that only asked about specific classes of indicators (only soil fertility or only plant indicators), the most frequently mentioned indicators were the presence of indicator plants; fallow age; the presence of dense trees/ground shade, and vegetation composition (Table 1).

Four reports ranked the indicators used by farmers to determine when to crop a fallow. Here, vegetation descriptors predominated with fallow age most frequently ranked first, followed by vegetation composition, the presence of indicator plants, and the presence of earthworm casts (Table 2).

Of the six studies dealing exclusively with soil-based indicators, those most frequently used were the presence of earthworm casts and soil colour, followed by soil structure/hardness and texture (Table 3). Earthworm casts were ranked as the fifth most frequent criterion of all types of parameters (Table 1).

53 indicator plant species were identified across all studies (Table 4). 37 plants were used as indicators of soil fertility and thus to cultivate the fallow. 13 plants indicated infertility and thus to avoid cultivating the fallow. 3 species indicated either fertility or infertility, depending on growth characteristics. The most exhaustive lists of indicator plants were reported from southern Cameroon (Carrière, 2002a,b; Carrière et al., 2002; Castro Carreño, 2001, quoted in Carrière and Castro Carreño, 2003), the Ashante region of Ghana (Dawoe et al., 2012) and south west Nigeria (Osunade, 1992).

The most frequently mentioned indicator plant species, listed in 10 areas (8 times as a soil fertility indicator, once as an indicator of infertility and once as either an indicator of fertility or

Table 1
Percentage frequency of inclusion and consequent ranking of indicators used by farmers for fallow selection. $N = 13$.

Attribute	% reports listing indicator	Rank
Presence of indicator plants	85	1
Fallow age	46	2
Presence dense trees/ground shade	31	3
Vegetation composition	23	4
Presence of earthworm casts	15	=5
Perceived time to dry	15	=5
Fallow estimated biomass	15	=5
Thickness of litter layer	15	=5
Soil colour	15	=5

Data sources: Adou Yao and Roussel (2007), Almy et al. (1991), Benneh (1972), Birang et al. (2003a), Bolakongo et al. (2013), Brown (2004), Henry (1979), Jurion and Henry (1967), Osunade (1992), Richards (1986), quoted in Ickowitz (2006), Richards (1985), quoted in Gleave (1996), and Tshibaka (1989).

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Table 2
Rank position of indicators used by farmers to indicate fallow choice. Refers only to those surveys including ranking criteria. $N = 4$.

Attribute	Rank (%)					% reports listing indicator
	1st	2nd	3rd	4th	5th or less	
Fallow age	75				25	100
Vegetation composition	25	25				50
Presence of indicator plants		75				75
Presence of earthworm casts			50			50
Perceived time for material to dry			50			50
Presence of dense trees/ground shade				25	25	50

Data sources: Birang et al. (2003a), Brown (2004) and Osunade (1992).

Table 3
Percentage frequency of inclusion and consequent ranking of soil fertility indicators used by farmers. $N = 7$.

Indicator	% reports listing indicator	Rank
Earthworm casts	71	=1
Soil colour	71	=1
Structure or hardness	43	=3
Texture	43	=3
Previous crop yield	29	5

Data sources: Adjei-Nsiah et al. (2004), Birmingham (2003), Dawoe et al. (2012), Maliki et al. (2012), Onweremadu et al. (2007), Quansah et al. (2001) and Saïdou et al. (2008).

infertility depending on the appearance of its leaves), was the Asteraceae shrub *Chromolaena odorata*. The trees *Triplochiton scleroxylon* (Sterculiaceae) and *Terminalia superba* (Combretaceae) and the grass *Pennisetum purpureum* (Poaceae) were each mentioned, generally as fertility indicators, in three regions. The grass *Imperata cylindrica* was mentioned as an indicator of infertility in three regions. Other species mentioned multiple times as indicators of fertility were the herb *Aframomum* sp. (Zingiberaceae), the grass *Andropogon gayanus* (Poaceae), and the trees *Ceiba pentandra* (Bombaceae), *Milicia excelsa* (Moraceae), *Triumfetta cordifolia* (Tiliaceae) and *Trema guineensis* (Ulmaceae).

4. Discussion

4.1. Fallow age and vegetation composition

Farmers ranked fallow age as the first or second criterion in fallow selection (Tables 1 and 2). This criterion has a strong biological basis. As fallows become older, their biomass and nutrient uptake from the soil will increase. Furthermore, with litterfall deposits, soil organic carbon and total nitrogen concentrations will generally increase. When older fallows are cleared, more nutrients have accumulated in the vegetation, which will either be released through burning and/or decomposition, depending on the biomass management strategy employed by the farmer. Accumulation rates vary between sites and ecoregions. Nye and Greenland (1960) measured fallows in the moist evergreen forest zone of Kade, Ghana and Yangambi in the now DRC and found that aboveground biomass ranged from 87 Mg ha^{-1} in 5-year-old fallows to 145 Mg ha^{-1} in 18-year-old fallows in DRC to 336 Mg ha^{-1} in 40-year-old secondary forest fallows in Ghana. Accumulation rates of biomass and nutrients over time may not necessarily be linear but approach a maximum so rates may decline in older fallows (Omeja et al., 2012; Silver et al., 2000). Nolte et al. (unpublished) modelled carbon and nutrient budgets for dominant fallow systems in the humid forest zone of southern Cameroon. Data fitted well in a regional model of a (false) chronosequence of biomass production and nutrient accumulation over time, even though there were differences in vegetation composition and soil type. Furthermore, as fallows become older, the viability of the weed seedbank decreases (Ikuenobe and Anoliefo, 2003; de Rouw, 1995), and potential crop pest and disease problems can be reduced if the fallow species are non- or less suitable hosts (Schroth et al., 2000). Thus, potential, yield-limiting factors, such as weed competition and pest and disease losses, are reduced.

However, various authors such as Gleave (1996), Mertz (2002) and Ickowitz (2006) have questioned the use of fallow age as an indicator of future crop yields. Mertz (2002) reviewed literature containing data on both fallow lengths and subsequent crop yields. Of the examples he found, only two were from West and Central Africa: maize yields in Côte d'Ivoire published by Slaats et al. (1998) and rice yields in Guinea (Wey and Traore, 1998). Yet, the number of ages of fallow plots was limited and is likely to be confounded with spatial variability. Assessments relying on false chronosequences imply high levels of spatial variability and interannual variation. A controlled experiment to avoid these two limitations would require identifying an area with uniform soil and vegetation, then cultivating plots in different years and thus having fallow succession start in different years. These fallows of different ages would then be cultivated simultaneously many years later and yields assessed. Such a study would require a large investment and long commitment.

4.2. Presence of indicator plants

Plant indicator species were one of the most important criteria used by farmers. According to Carrière (2002b), who carried out one of the most comprehensive of the studies, in southern Cameroon, plant indicators may be more reliable indicators of soil fertility than visible soil properties such as colour and texture, which tend to be highly spatially heterogeneous in the humid forest.

4.2.1. Chromolaena odorata

The most frequently cited, *C. odorata* is a perennial, heliophilous shrub (King and Robinson, 1970). It is native to South America and invasive elsewhere. It was introduced to western Africa in the first half of 20th century (Gautier, 1992) and is widely distributed throughout the humid forest and transition zones. At savannah–forest boundaries, it can invade savannah (Guillet et al., 2001) and create shaded conditions under which tree saplings could potentially establish. Thus while being a major weed, it has been cited as a fallow species (Koné et al., 2012; Koutika and Rainey, 2010).

The perception of a positive correlation between *C. odorata* presence and higher soil potential is widespread. In the Ashante region of Ghana, farmers distinguished between *C. odorata* with "large green leaves" as an indicator of soil fertility whereas with "small yellow leaves" it was considered an indicator of infertility (Dawoe et al., 2012). *C. odorata* has high phenotypic plasticity (Witkowski and Wilson, 2001) and thus the appearance of its leaves may indicate soil nutrient concentrations, particularly nitrogen.

In central and southern Cameroon, Ngobo (2002) found strong positive correlations between soil N and total C contents and *C.*

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Table 4
Plant indicators of soil fertility (+) or infertility (−) reported from interviews with or observations of smallholder farmers in West and Central Africa.

Species	Regions																		Sum	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	(+)	(−)
																			Per spp.	
Chromolaena odorata				+	+/−[a]	+			+	+	+		+	−		+	+		9	2
Triplochiton scleroxylon					+/−			+								+			3	1
Terminalia superba					+			+								+			3	0
Pennisetum purpureum				+			+				+								3	0
Imperata cylindrica				−		−						−							0	3
Aframomum sp.															+[b]	+			2	0
Andropogon gayanus						+	+												2	0
Ceiba pentandra					+/−											+			2	1
Milicia excelsa					+											+			2	0
Triumfetta cordifolia															+	+			2	0
Trema guineensis								+								+			2	0
Cassia alata															+				1	0
Cassia occidentale															−				0	1
Cola cordifolia								+											1	0
Cola gigantea					−														0	1
Ageratum conyzoides																+			1	0
Alstonia boonei					+														1	0
Antiaris toxicaria					−														0	1
Aspilia latifolia								+											1	0
Cedrela odorata					−														0	1
Celtis mildbraedii					−														0	1
Centrosema pubescens							+												1	0
Combretum sp.																+			1	0
Desbordesia glaucescens																+			1	0
Dicrostachys nutans															−				0	1
Dioscorea bulbifera																+			1	0
Eribroma oblonga																+			1	0
Erythrophleum suaveolens																−			0	1
Ficus asperifolia								+											1	0
Funtumia elastica								+											1	0
Hymenocardia ulmoides																		+	1	0
Hyptis spp.						−													0	1
Indigofera secundiflora						+													1	0
Ipomoea involucrata																+			1	0
Morinda lucida								+											1	0
Musanga cecropioides																		+	1	0
Newbouldia laevis								+											1	0
Palisota ambigua																+			1	0
Panicum maximum							+												1	0
Penthaclethra macrophylla																+			1	0
Piptadeniastrum africanum																			0	1
Pterocarpus soyauxii																+			1	0
Pycnanthus angolensis																+			1	0
Rauwolfia vomitoria															+[c]				1	0
Sida acuta																+			1	0
Sondias monbin								+											1	0
Sorghum arundinaceum											+								1	0
Spermacoce filifolia						−													0	1
Striga hermonthica						−													0	1
Supubia ramosa			−																0	1
Thaumatococcus danielli		+																	1	0
Tragia benthami																+			1	0
Trilepisium madagascariense					+														1	0
(Absence of grasses)	+																		1	0

[1]Mogbuama, central Sierra Leone, [2]S Côte d'Ivoire, [3]Ghana transition zone, [4]transition zone, Wenchi, Ghana, [5]Ashante region, Ghana, [6]transition zone, Benin, [7]S Benin, [8]Irewole, Oyo State, SW Nigeria, [9]Abia and Imo States, SE Nigeria, [10]Mamfé, SW Cameroon, [11]Kumba, SW Cameroon, [12]transition zone, Mouanguel, Littoral Province Cameroon, [13]Nkometou, central Cameroon, [14]Akok, S Cameroon, [15]S Cameroon (unspecified, area with Bulu ethnicity), [16]Nkongmeyos, S Cameroon, [17]Mayombe region, Republic of Congo, [18]Kisangani region, E Democratic Republic of Congo.

References: [1]Richards (1986), quoted in Ickowitz (2006); [2]Hédin (1932); [3]Benneh (1972); [4]Adjei-Nsiah et al. (2004); [5]Dawoe et al. (2012); [6] Saïdou et al. (2008); [7]Vissoh et al. (2007); [8]Osunade (1992); [9]Onweremadu et al. (2007); [10]Almy et al. (1991); [11]Almy et al. (1991); [12]Yonghachea (2005); [13]Brown (2004); [14]Brown (2006); [15]Hédin (1932); [16] Carrière (2002a,b), Carrière et al. (2002), Castro Carreño (2001), quoted in Carrière and Castro Carreño (2003); [17]Guili, 1989, quoted in Moutsambоté et al. (2000), [18]Henry, 1979, Jurion and Henry (1967), Bolakongo et al. (2013).

Codes:

[a] If large green leaves then (+); if small yellow leaves then (−).
[b] If dense.
[c] If good size.

odorata abundance. Furthermore, Ngobo et al. (2004) found that fallows where *C. odorata* was dominant did indeed have significantly higher following crop yields (maize, groundnut, cassava) than fallows of the same duration with little *C. odorata*, thus supporting its use as an indicator. To what extent *C. odorata* actually improves soil fertility or just tends to colonise more fertile land, which has not been reliably tested, is immaterial in the context of being an indicator. Counter-intuitively, Ngobo et al. (2004) also

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found that young fallows where the preceding fallow was a long secondary forest had higher frequencies of *C. odorata* than fallows where the previous fallow was also a (short) *C. odorata* fallow, supporting the idea of *C. odorata* being an indicator of land that has not been subjected to so many slash and burn cycles and thus land of higher potential. Ikuenobe and Anoliefo (2003), working in southern Nigeria, showed that removal of *C. odorata* from fallows caused grass invasion. As a highly visible and dominant plant, *C. odorata* is easy to identify and therefore can serve as an indicator.

4.2.2. Grasses

Here, *I. cylindrica* presence was listed as an indicator of fallows to avoid in three transition zone areas. *I. cylindrica* dominance has been associated with poor soils in south-east Asia (De Foresta and Michon, 1997) and is reportedly an indicator of poor soil in the Tanala region of Madagascar (Rakotoson et al., 2009). In the savannah transition zone of West Africa, it is considered by farmers to be the most serious weed of cropped fields (Chikoye et al., 2000). Elsewhere, it has been shown to be highly effective at competing for nitrogen (Brewer and Cralle, 2003) and also inter-specific penetration of its rhizomes cause injury to neighbouring plants, accentuating its competitiveness (Holly and Ervin, 2006).

P. purpureum was mentioned as an indicator of fertility, exclusively in forest–savannah transition zones. This grass has been reported to outcompete *I. cylindrica* in the presence of fire in Uganda and to indicate richer soils (Thomas, 1946). Furthermore, as it is native to tropical Africa in areas with precipitation exceeding 1000 mm p.a. (Brunken, 1977), its use as an indicator in the drier transition zone, at the limits of its distribution, may indicate higher local water availability and thus good conditions for crop cultivation.

4.2.3. Herbs

In southern Cameroon, *Ageratum conyzoides* (Asteraceae), an invasive weed, was referred to as an indicator of soil fertility (Castro Carreño, 2001, quoted in Carrière and Castro Carreño, 2003). In studies in southern Nigeria, Ikuenobe and Anoliefo (2003) found that this broadleaf species and others are promoted by *C. odorata* fallows: on the contrary, when *C. odorata* was removed experimentally from fallows, less desirable grass species became dominant. *Afromomum* spp. are used as indicators in the Tanala region of Madagascar (Rakotoson et al., 2009). In Cameroon, it is considered indicative of fallows where the preceding fallow was a secondary forest, rather than a plot derived from a cycle of short fallows (Tchiengué, 2012), hence suggesting a more fertile plot.

4.2.4. Tree species as indicators

Many of the tree species cited, such as *Musanga cecropioides*, *T. guineensis* and *T. scleroxylon*, are pioneers (sensu Swaine and Whitmore, 1988). Ngobo et al. (2004) found that, in Cameroon, *M. cecropioides* and *T. guineensis* were both associated with soils of higher clay, N, and C contents. According to Fayolle et al. (2012), *M. cecropioides* is one of the five most frequent species in the Congo Basin forest limited to regions where the mean annual rainfall exceeds 1500 mm. Hall and Okali (1979) report it is only found where the soil fertility has not been lowered through intensive farming, supporting its indicator status.

T. scleroxylon, another pioneer (Keay, 1957), is widespread in the forest zone north of the Equator from Sierra Leone to Gabon and is far more frequent on higher fertility soils (Veenendaal et al., 1996) with higher base saturation and at least 1100 mm p.a. rainfall (Hall and Bada, 1979). Fayolle et al. (2012) support this by saying that trees are associated with high fertility soils. In south west Nigeria, higher abundances of *Morinda lucida* and *Newbouldia laevis*, also used as indicators, do indicate more fertile Egbeda-series soils (Smyth and Montgomery, 1962, quoted in Hall and Okali, 1979).

One notable exception was *Funtumia elastica*, a climax, light demanding species (Kyereh et al., 1999), cited as an indicator in south west Nigeria (Osunade, 1992). According to Hall and Okali (1979), its abundance indicates favourable conditions for recultivation as it tends to occur in areas where land use has not been intensified.

4.3. Vegetation composition and tree density

Other indicators quoted by farmers were composition and tree density. For example, farmers in the Kisangani region of Eastern DR Congo estimate when to recultivate land by the diameter of the *M. cecropioides* trees, and the biomass of the undergrowth. They clear when they are able to walk easily under the trees (Jurion and Henry, 1967). *M. cecropioides* has soft wood with a high water content and is easy to cut and, that, along with little understorey vegetation may signify reduced labour requirements for clearance.

4.4. Presence of earthworm casts

Earthworm casts were the most frequently used soil criterion used by farmers. Earthworms comprise 40–90% of the soil macrofaunal biomass in most tropical ecosystems, except under intensively cultivated annual crops (Fragoso et al., 1999). Indeed, when land is cleared, slashed and burned, earthworm density, diversity and activity are generally perceived to reduce, with some examples of this occurring in West and Central Africa (for example, Critchley et al., 1979; Norgrove et al., 1998). Hauser et al. (2012) conducted a meta-analysis of data on cast production from these regions, separated by the dominant USDA soil classification. Data assessed were from the low-fertility Ultisols and medium-fertility Alfisols and Entisols. They found that a severe decline in production during the cropping phase was more a feature of Ultisols. Tondoh et al. (2007), working in Côte d'Ivoire on an Oxisol, found that earthworm density and biomass was higher in 20-year-old fallows than in young (2–5 years old) recurrent fallows, although the latter had similar density and biomass to cropped fields. Birang et al. (2003b) found more cast production at an Ultisol site (Metet, southern Cameroon) in 4–5-year-old *C. odorata* fallows than 10–12-year-old bush fallows. No correlation has been found in the literature demonstrating any relationship between in situ deposited cast amounts and the following crop parameters (Hauser et al., 2012). However, casts signify the presence of earthworms, generally found to have positive effects on tropical crop yield (Spain et al., 1992) and the application of casts has been demonstrated to increase yield in Cameroon (Norgrove and Hauser, 1999b). The features of cast production, i.e. the deposition of enriched material, which is much richer in nutrients than the bulk soil, at the soil surface, and the resultant increase in soil porosity, will in itself increase soil fertility and thus can be a reliable indicator, particularly on Ultisols, if differences in soil classification are accounted for.

4.5. Autocorrelations between indicators

Indicators can be to some extent, autocorrelated. For example, earthworm cast production is higher where the soil is shaded by vegetation, such as *C. odorata* stands (Birang et al., 2003b) and in areas with higher *C. odorata* biomass (Norgrove and Hauser, 1999a). In Wenchi, Ghana, farmers also linked the presence of *C. odorata* and earthworm casts as both indicating good soils. They made a mechanistic connection, stating that *C. odorata* provides high quality litter input, and creates a shady and moist environment and these are factors which increase earthworm activity (Adjei-Nsiah et al., 2004).

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In southern Cameroon, in a cropped field, it was found that weed biomass, dominated by *C. odorata* explained 76% of the variation in cast production (Norgrove and Hauser, 1999a). In another trial, Norgrove et al. (2003) found that mulching with *C. odorata* increased cast production and they had higher nitrogen (N) and potassium (K) concentrations than those from non-mulched controls. It thus seems likely that the worms were feeding on the N and K rich *C. odorata* residue. Likewise, In NW Cameroon, fallows invaded by *C. odorata* had more than double the aboveground biomass of non-invaded areas and its leaves were relatively rich in both N (40 mg g^{-1}) and K (23 mg g^{-1}) (Yonghachea, 2005) thus nutrient uptake was much greater. Higher earthworm densities were found in these *C. odorata*-invaded sites (Norgrove et al., 2008). Similar results, with improved soil properties and increased densities of earthworms in areas invaded by *C. odorata*, were found by Tondoh et al. (2013) in the forest–savannah transition zone of Côte d'Ivoire.

5. Conclusions

Farmers in West and Central Africa have identified indicators for selecting which fallow plots to recultivate. They have some logical scientific basis and are broadly supported by scientific studies from the West and Central African region. There was consistency across studies suggesting that some (fallow age, the presence of *C. odorata*, earthworm casts) could be used across the region, while others, for example, the use of *I. cylindrica* and *P. purpureum* as negative and positive indicators, are specific to the drier forest–savannah transition zone. This research demonstrates the relative paucity of documentation of farmers' knowledge in the region yet confirms the quality of ecological knowledge used. More studies should be conducted to fill this gap and such knowledge should form the foundation of any suggested improvements to farming systems in the region as well as providing information to farmers in communities where such knowledge is not currently applied.

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