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Accessing and assessing legacy soil information, an example from two provinces of Zambia

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ABSTRACT

Soil information is essential for agricultural research and development. In developing countries like Zambia, the availability of soil information is limited by the cost of new soil surveys. Legacy soil information could be useful to fill this gap. This study evaluated the availability of legacy soil information in Southern and Eastern Provinces of Zambia. We also examined the survey scales, legends, boundary density and map texture. We examined a number of exemplar transects undertaken by C.G. Trapnell from 1932 to 1942 in the region, evaluating the information provided on soil, vegetation, landscape and farming systems. An overview of this legacy was presented to a workshop of varied stakeholders in Lusaka, and their opinions on its utility were elicited. More than 60% of large-scale surveys known to have been conducted in the two provinces could not be traced and among those traced some map-sheets were not available. Most of the survey reports exist as hard copies and some are in poor condition, while only 7 are available online on the ISRIC website as scanned copies. The map scale and texture were not entirely consistent with general expectations, with map texture consistent with a smaller publication scale in assessed map-sheets. Stakeholders regarded the legacy information as a valuable resource, despite some limitations, suggesting that some of its features could usefully be reproduced in modern soil information. The holistic assessment provided for soil map units may be more accessible than single-property maps. Accessibility and understanding of soil information is seen as a limitation. There is an urgent need to preserve the legacy soil survey reports and maps that are still available in Zambia, and in other countries. This entails physical preservation of material, making it available, and studying it closely with current and retired soil surveyors to preserve their recollection of how it was produced and their understanding of how it should be interpreted. The preservation should include scanning of hardcopy reports and storage in national, regional, and global soil survey data hubs with links provided for easy access. Stakeholder enthusiasm for the format of legacy soil surveys suggests that renewed systematic soils surveys would be valuable.

1. Introduction

The critical role soils play in food security and ecosystem services is widely recognised such that the United Nations declared 2015 as the international year of soils (FAO, 2015; Wall and Six, 2015). In view of this, regional- and country-specific initiatives have been renewed to collate current and legacy soil information to support research for development. Recent advances in information technology have improved the management and creation of databases for soil information particularly legacy data for soil properties (Leenaars, 2013; Nachtergaele et al., 2010). Information on individual soil properties is invaluable. However, on its own it is likely to be of limited use for land management. Conventional classification-based soil survey presented the soil surveyor's conceptual model of the soil, their expert interpretation and the information they gleaned from their interactions with local farmers, agronomists and others (Beckett and Bie, 1978). Useful soil information will have such a conceptual framework to facilitate the interpretation of data (Campbell et al, 2017).

It is widely recognized that countries like Zambia, and others in Africa, have a deficit of soil information (e.g. Van Ranst et al., 2010), with very little at the larger scales needed for development and project planning. There are various reasons why this information is lacking, and

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these are reviewed by Van Ranst et al (2010). These authors note that the last few decades of the last century saw a global decline in soil survey, such that FAO no longer carried out a global programme of collecting soil information by the end of the century, and little other effort was devoted to the collection of primary data. They attribute this, in part, to a lack of funding, but also to poor presentation of soil information to the general user. Since then, much effort has been devoted to mapping soil properties from existing data by digital techniques with some collection of new soil information to support this in Africa (e.g. Leenaars et al., 2018). However, Van Ranst et al. (2010) note that it is not clear that the adoption of this new technology has necessarily made information more accessible or useful to the user. It is for this reason that we have undertaken a project on the history of soil surveys in Zambia, looking at survey products from the colonial period and conventional soil maps produced post-independence (Mukumbuta et al., 2021). Our objective has been to evaluate this legacy soil information in collaboration with contemporary stakeholders, to consider its value both for modern-day application and as a model for the collection and presentation of new information.

In much of Africa soil surveys were conducted pre-independence by colonial governments. After independence these survey activities continues, often undertaken by local soil surveyors with technical support from international agencies (Dalal-Clayton and Dent, 1993; Young, 2017). It has been proposed that this legacy soil information is potentially useful today to support decisions on land management or to help target extension programmes, and for many developing countries legacy surveys could be the only source of soil information at certain localities (Cambule et al., 2015). Even in places where soil information is readily available, legacy soil information can provide important background (Dent and Ahmed, 1995) and can be used to track changes in soil characteristics over time (Rossiter, 2008).

Given the potential value of legacy soil information, there has been considerable interest in its evaluation for contemporary application. Protocols have been developed to assess the accuracy and usefulness of legacy soil information (e.g. Forbes et al. 1987) and some previous work has examined specific legacy surveys (e.g. Ahmed and Dent, 1997; Cambule et al., 2015). There have also been studies on legacy information in particular countries like Croatia (Hengl and Husnjak, 2006) and Iran (Rasaei et al., 2020). However, we are not aware of any previous study which has attempted an overall inventory and assessment of the legacy of soil information for regions of sub-Saharan Africa. In this study we set out to examine the legacy soil information in two provinces of Zambia as an exploratory study to assess the general qualityof such information, challenges for its recovery and to present it to contemporary stakeholders engaged in agricultural research and development to see how they assessed its value.

Much legacy soil information was produced in Zambia pre- and post-independence. Zambia also played an important role in the development of soil survey in Africa (Tilley, 2011), notably through the work of Trapnell and colleagues (Trapnell et al., 1947), and early applications of air photography (Robbins, 1934). However, other countries in sub-Saharan Africa, and elsewhere, also have a legacy of soil survey materials from the colonial and post-colonial periods (Young, 2017) and so a systematic study of this information in Zambia will be of more generic relevance. In this study we set out to inventorize and make initial evaluations of large-scale legacy soil survey information for Southern Province and Eastern Province of Zambia (Fig. 1) to assess the challenges and potential value of such resources. We aimed to answer the following questions; What information is available? How accessible is the information? In what format and condition is the information? How do the mapped soil boundaries compare with international standards and comparisons as set out by Bie and Beckett (1971) and Forbes et al (1987)? We also evaluated the traverse records of Trapnell, collected from 1932 to 1942, (Smith and Trapnell, 2002) and assessed how much useful soil information the records contain. Finally, we presented some exemplar legacy soil information to a diverse stakeholder group and recorded their opinions on the potential value of legacy survey information in a structured questionnaire.

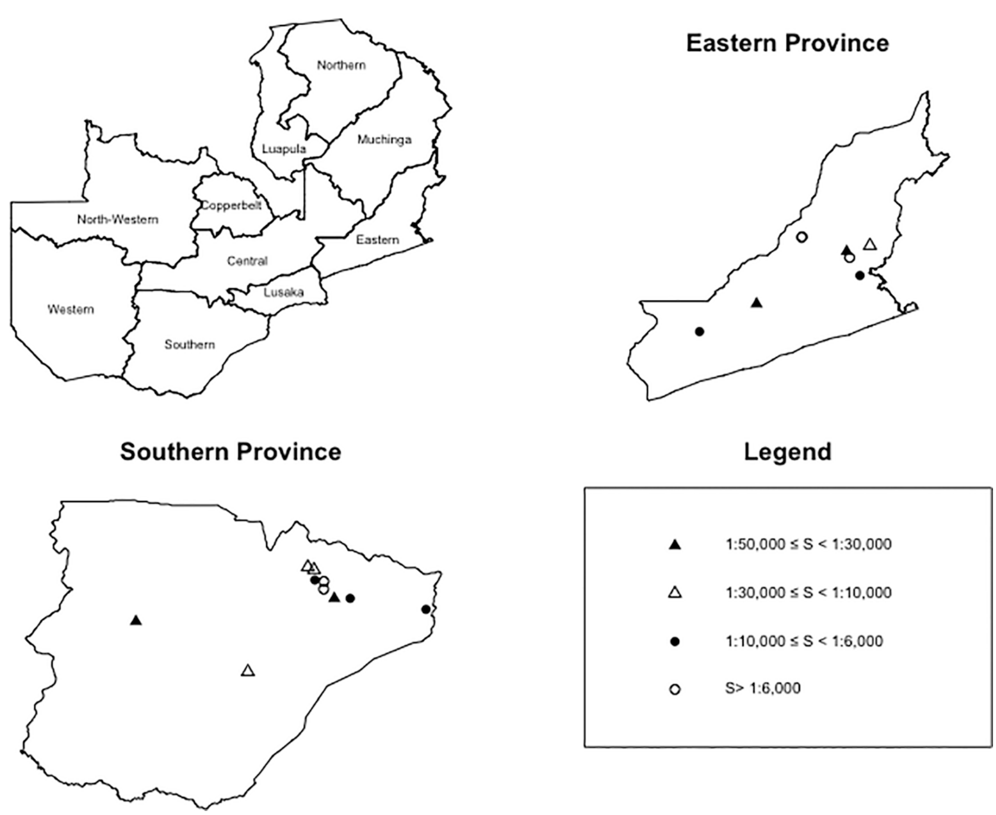

Fig. 1. Locations and scale of some of the identified legacy soil surveys in Eastern and Southern provinces of Zambia evaluated in this study.

2. Materials and methods

2.1. Study area

Eastern Province and Southern Province of Zambia (Fig. 1) were selected as target areas for the evaluation of legacy soil information this study. This was because of the perceived requirement for soil information, and its potential value for small-holder farmers in these areas which are the top two provinces for the production of maize, a staple crop in Zambia (IAPRI, 2015). Eastern province is 51,476 km^2 and Southern province is 68,410 km^2 so between them they constitute 16% of the area of the country. Both provinces largely fall within Zambian Agroclimatic zone II (Saasa, 2003; Veldkamp et al., 1984), with small areas within zone I. The annual rainfall in Agroclimatic zone II ranges from 800 to 1000 mm per annum, so that the drought-risk is low to medium, and the growing season is typically 100 – 140 days in length. In contrast, zone I, in the major valleys and southern part of Southern Province receives on average less than 800 mm annual rainfall, and the growing season is typically 80 – 129 days.

2.2. Identification, selection and reading of legacy soil surveys in the area.

2.2.1. Inventorization of large-scale legacy information.

We conducted an inventory of the existing legacy soil surveys and information in the target region. The first step was to form a list of all large-scale soil surveys (meaning by this, all surveys of areas smaller than the province as a whole). This list was based on an index of surveys at the Zambia Agricultural Research Institute (ZARI) and the evaluation report on soil surveys in Zambia made by the Norwegian Agency for Development Cooperation (NORAD, 1981). We then looked for the memoirs and map-sheets of these surveys at ZARI's soil survey section, which is the custodian of legacy soil information in Zambia. Additional searches for survey materials were made at the University of Zambia (UNZA) Department of Soil Science, and online at the ISRIC repository (https://www.isric.org/explore/library). We also examined the EUDASM archive (https://esdac.jrc.ec.europa.eu, Panagos et al., 2011) which contains some Zambian material, but most of this is at small cartographic scale, and there were no surveys within our target provinces, or surveys in the ZARI soil survey section series. This allowed us to complete the inventory with a listing of all accessible large-scale soil surveys including the format of the report (soft or hard copy), year of publication, and the type of report available (map-sheet and/or memoir). Due to the COVID 19 pandemic there was limited scope to search further for material in other locations (e.g. in Provincial libraries or archives). However, we consider that the availability of soil survey records in the archive of the national agency responsible for soil information, and at the national University, is a good measure of its accessibility to stakeholders such as government departments and NGOs.

Thereafter a detailed protocol for reading and extracting information was prepared (Annex 1 in the supplementary material). The protocol was a checklist of questions which included the following: What was the scale and effort of the survey under consideration? How was the sampling designed? What soil properties were mapped? What soil classification was used and was any land evaluation conducted?

We identified four surveys which provided information on which to estimate the survey effort (total staff days) required to complete the field work. These were used for comparison with the effort/scale relationships developed for surveys across Australia by Bie and Beckett (1971). In addition, six survey map-sheets, in a reasonable state of preservation, were used to estimate quality criteria presented by Bie and Beckett (1971) and Forbes et al. (1987). These map-sheets were scanned and georeferenced.

2.2.2. Trapnell traverse records and soil-vegetation map

In addition to the large-scale surveys discussed in the previous section, we examined the information on soils, vegetation and farming systems at locations within modern-day Eastern Province and Southern Province in the field records of C.G. Trapnell. Trapnell and other staff from the colonial administration conducted field reconnaissance surveys in various parts of Zambia, then called Northern Rhodesia, between 1932 and 1944. These field surveys provided the basis for two reports on soils, vegetation and farming practices first published by Trapnell and colleagues in the 1930 s and 1940 s (Trapnell, 1996; Trapnell and Clothier, 1996). A vegetation-soil map of the whole country (Trapnell et al., 1947) presents all this information cartographically and in a memoir. The traverse records have since been published (Smith and Trapnell, 2002), but we are not aware of any studies which have examined the published records as legacy soil and farm-system information, or related them to the map-sheets of Trapnell et al. (1947). In order to assess the potential value of the information for modern-day stakeholders we extracted example material as follows. Three traverses, Serenje–Petauke–Mkushi–Kapiri Mposhi traverse of August 1940, Chipata–Katete–Petauke traverse (year unknown), and the Southern and Central province road traverse of 1933–1934, were selected. The survey records provide descriptions of soils, vegetation and farming systems at locations on the traverse. We first allocated the locations at which information is recorded to map units of the vegetation-soil map of Trapnell et al. (1947). We then extracted information specifically on soils and on farming systems. The procedure was as follows.

i. Identification of Trapnell vegetation-soil map units

The published Trapnell records (Smith and Trapnell, 2002) provide longitude and latitudes inferred or recorded for multiple locations along each of the traverses. We refer to these as waymarks. The waymarks, on each of the selected traverses were extracted into a spreadsheet along with the corresponding place name, district, and the date of the observation. The waymarks were then displayed on the scanned and georeferenced map-sheets of Trapnell et al. (1947) and the corresponding map unit was extracted through visual observation. This was done critically, accepting the element of approximation in the coordinates given by Smith and Trapnell (2002) and the likely limitations on the geodetic quality of the map-sheets from 1947. The description of vegetation at each site was therefore used to check the plausibility of the map unit identified. For locations that fell on the boundary of two different map units or those with coordinates not given in the published record, the mention of key specific vegetation types was important for distinguishing and inferring the vegetation classes. For example, references to *Commiphora* were key to distinguishing classes L2 and L3 over the lower valley soils of the Luangwa valley. Additionally, the vegetation-soil map units for points without coordinates were inferred from the information recorded such as relative distance and position from locations with known coordinates and the vegetation-soil description recorded in the traverse records.

As many descriptions of soil and vegetation recorded in Trapnell's notes were associated with sections of the traverse between recorded waymarks with locations, and some sections of the traverse crossed back and forth between map units, it was important to use all information available to infer the most likely vegetation-soil class associated with each recorded observation rather than interpolating mechanically between the waymarks, so that even if a description of a section or site was between two waymarks in the same map unit, it was necessary to reflect critically, with reference to the map-sheets and descriptions of the vegetation, whether the described sections could be plausibly allocated to the same unit. For example, in the Kalomo to Macha Mission traverse from 1933, illustrated in Fig. 3, co-ordinates are infrequent, but from those we have we can see that the traverse starts on watershed types (unit S4) at Kalomo and ends on Upper Valley soils (U2) at Macha, with most of the intervening locations on Plateau soils (P7). However, at one location, clearly between P7 sites, the location is described as transitional fringe with fertile chocolate sandy loam and Hyparrhenia grass, more likely to reflect a site transitional between P7 and S4.

The description of the different sections along the traverses were mostly divided and described chronologically based on the date or set of consecutive dates the survey was conducted. However, in some cases, such as with the Chipata-Katete-Petauke traverse the surveyors stayed at one central location throughout the survey such that some locations related in terms of the topography or geographical location were surveyed on different days/trips. Therefore, to capture the variations among related points, the locations were divided into sections and described based on the geographical locations on the map without necessarily following the chronological order as recorded in the traverse records.

ii. Extraction and interpretation of soil information

The first step was to scan the traverses and record the places or sections of the traverses and the page numbers where soil information, such as colour and texture, was recorded. This was followed by a thorough reading and extraction of the actual soil information. The soil properties, which in most cases were the soil colour and texture, and in some instances included geological or mineralogical information, were then extracted together with the associated primary vegetation and information on the landscape position of the observation (e.g. dambo, hill toe-slope, stream edge). Additionally, other soil-related information such as constraints on soil use or soil quality (e.g. presence of extensive erosion, fertility status etc) was recorded.

The next step was then to make a general interpretation of the soil-vegetation-landscape variation along the traverse section. This included the variations in soils within a given vegetation-soil map unit (e.g. P7) associated, for example, with variation in landform and/or the differences in soil properties between the different vegetation-soil map units examined along a section of a traverse.

iii. Extraction of farming systems information

The aim of this section was to identify the farming systems including the crops grown and principles of soil selection, management practices, sequence of cropping and rotations, number of years a site was cultivated and fallow periods and any other related information. Like the extraction of soil information, the first step was to scan through the traverse records to identify places where information of cropping systems is recorded followed by a close reading and summary of the information itself.

2.3. Evaluation of large-scale legacy information

We recorded the information provided about map units for those surveys for which the memoirs were recoverable. For a subset of map-sheets we conducted further measurements to compare the texture and intricacy of the mapped boundaries with international standards as set out by Bie and Beckett (1971) and Forbes et al. (1987). This was to see whether the mapped pattern of soils would be broadly regarded as consistent with the published scale of the map.

2.3.1. Maps and their legends.

For each accessed survey we recorded the published scale, the surveyed area (where presented in the memoir), the survey type as identified in the memoir (Detailed, Semi-Detailed, Reconnaissance) and the purposes of the survey. In addition, we recorded the number of legend units, the soil classification on which they were based and whether they were simple (i.e. one dominant class for which each unit was named) or complex (i.e. explicitly defined as an assemblage of two or more classes). We also recorded whether land capability assessments were made for the units.

2.3.2. Average size delineation (ASD)

Selected map-sheets were scanned and georeferenced for further study. Following Forbes et al. (1987) we estimated the average size delineation (*ASD*), i.e. the average size on the map of the delineations or polygons, in cm^2. This was estimated by the procedure of Forbes et al. (1987) in which a circle of radius 2.5 cm was placed at random on the map, but so that its entire area fell within the map. The total number of continuous polygons occurring partly or wholly within the circle was counted so that if a single polygon on the map appeared in two segments disconnected within the circle this was counted as two polygons. This was repeated to give a total number of counts (m) in 5 independently placed circles. The *ASD* was then estimated from the following:

$$ASD = 1/b, \tag{1}$$

where.

$$b = (m/A) - c$$

and A and c are constants with values of 142 and 0.1 radius, respectively for a circle of 2.5 cm.

2.3.3. Index of maximum reduction (IMR).

The scale at which a soil map is published should reflect the intricacy of the soil pattern which is portrayed. This is implicit in the relations between map scale and factors such as boundary density or survey effort observed by Bie and Beckett (1971) and implicit in soil survey organization guidelines (e.g. Gunn et al., 1988). Forbes et al. (1987) propose an index based on the *ASD*, the index of maximum reduction (*IMR*), which can be regarded as a measure of the suitability of the map scale for portraying a particular set of map units. The *IMR* is the factor by which the map scale can be reduced before *ASD* equals the minimum legible delineation area (*MLD*). If the *IMR* is smaller than a value of about 2.0 then Forbes et al. (1987) suggest that the map scale is small. The *IMR* was calculated as described by Forbes et al. (1987), taking *MLD* as 0.4 cm^2.

$$IMR = \sqrt{ASD/MLD} \tag{2}$$

2.3.4. Boundary density. *Boundary density, related to map intricacy, is the mean length of map boundary per unit area of map. It was calculated by applying Buffon's needle as described by Beckett and Bie (1975) and outlined below.*

First, random lines of 5 cm length on the published map scale were drawn on each of the maps. In each instance the starting point and direction of each line were randomly generated using the Geosphere package in R, and then the generated coordinates for each line were drawn on the geo-refenced maps. For each line the total number of times it crossed a soil map unit boundary (intersections) were counted. The boundary density (D) was then estimated by.

$$D = \pi I/(2S) \tag{3}$$

Where I is the total number of intersections; S is the sum of distance of the total number the lines required to reach the I intersections and the standard error of the boundary density is given by.

$$SE = \pi I^{0.5}/(2S) \tag{4}$$

Bie and Beckett (1971) found a consistent relationship between map scale and map boundary intricacy, the latter measured by the number of intersections per unit length of line where one unit on the map is equivalent to 1 km on the ground. They represented this by a regression line, and we compared the measured intricacy with the value predicted from the cartographic scale of each map.

2.3.5. Estimation of survey effort of selected legacy soil surveys

The memoirs of four of the surveys explicitly stated the amount of staff staff time used to produce them (staff-days). On this basis survey effort was computed as staff days per km^2. Bie and Beckett (1971) found that the map-scale and survey effort are typically related and they obtained a regression of effort on scale, the predictions from which we compared with the computed survey effort for the four surveys.

2.4. Evaluation of current utility of legacy soil information

We held a workshop for a diverse set of stakeholders to elicit their opinions about the utility of legacy soil information which were recorded in a structured questionnaire. The stakeholders included farmers, NGOs, agronomists, researchers, and policy makers. It was necessary to hold this workshop in a virtual format because of public health regulations imposed as a result of the COVID-19 pandemic, which was not ideal. A presentation was given on soil information in general and then more detailed presentations of selected legacy surveys and the Trapnell survey and information it provides on soils and historical systems were delivered. The presentations were followed by online discussion, and participants were given guidance on completion of the questionnaire. The relevant sections of the questionnaire for this study are presented in Annex 2 of the supplementary information. Once the questionnaires were returned they were anonymised and response coded and aggregated for analysis. Ethical approval for this part of the work was granted by University of Zambia (REF NO. NASREC-2020_NOV-005) and University of Nottingham School of Biosciences (Code: SBREC200111FEO).

3. Results and discussion

3.1. Availability of legacy soil information

The inventory of legacy soil information in the study area identified a total of 56 legacy soil surveys for Southern and Eastern Provinces. These are listed in Tables 1a, 1b and 1c and the locations for some of the surveys are shown in Fig. 1.

Of these 56 surveys we were able to recover both map sheets and the accompanying memoir for just 13 (22%). We were able to recover memoirs but no mapsheets for an additional 5 (14%). These 18 surveys are listed in Tables 1a and 1b. The remaining 38 surveys (64%), for which neither maps sheets nor memoirs could be traced, are listed in Table 1c. Note thatsome information, such as the authors' names, survey report numbers, year of survey, and type of survey was accessed for 8 of these surveys from references in other reports or memoirs, and this is recorded in Table 1c. The proportions of the total inventory for which different elements were recovered is represented in Fig. 2.

Most of the survey reports which were recovered exist as hard copies and only 7 of them could be found as scanned copies online on the ISRIC library (https://www.isric.org/explore/library). Several of these hard copy reports were in poor physical condition, and it is therefore important that they are digitized if they are to be preserved.

As observed by Rossiter (2008), it is important not only to rescue legacy soil resources by digitizing them, but they must also be georeferenced and made available online. There is no online or other digital repository of legacy and contemporary soil information in Zambia, and our experience suggests that the preservation of what reports can be recovered, their georeferencing and dissemination through online repositories is a matter of urgency.

Table 1a
Legacy soil surveys identified in Eastern and Southern Provinces of Zambia.

	Short name	Soil Survey report No.	Lead author	Year	Memoir found?	Map found?	ISRIC	Type	Size (ha)	Map Scale	Purpose of survey
1	Upper Kaleya	4a	Mumba	1971	Y	Y	Y	D	unknown	1:10,000	Land capability for small-holder agriculture
2	Heales Estate	5a	Mumba	1971	Y	Y	Y	D	unknown	[1] 1:10,000	Soil suitability for intensive maize
3	Nakambala 2nd Ext.	10	Brammer Dalal-Clayton	1972	Y	N	N	D	935	1:30,000	Agricultural suitability of soils
4	Sasare Block	12	Commissaris	1974	Y	N	Y	S-D	5620	unknown	Land capability for small-holder agriculture
5	Nakambala 3rd Ext.	13	Njøs	1973	Y	N	N	D	300	1:30,000	Agricultural suitability of soils
6	Pemba Village	16	Commissaris	1974	Y	Y	N	D	300	1:5,500	Investigate agricultural potential
7	Mochipapa	20	Schmidt & Njøs	1974	Y	N	Y	D	480	1:5,000	Land suitability for field trials
8	Nakambala 4th extension	25	Njøs	1974	Y	N	N	S-D	1448	?	?
9	Masumba	27	Commissaris	1975	Y	Y	N	D	250	1:5,700	Investigate soils and their extent for research trials under specific valley conditions
10	Magoye	46	Chinene	1977	Y	Y	N	D	711	1:11,000	Soil classification for agricultural research programmes
11	Nakambala 5th Ext.	48	Storrø	1978/80	Y	Y	Y	D	4179	1:10,000	Land capability for rain-fed and irrigated production.
12	Sikaleta-Nanzhila	63	Wennerby	1980	Y	Y	Y	R	243,870	1:50,000	General land capability
13	Zambezi Ranching	72	Storrø	1980	Y	Y	Y	R/pD	11,930	1:30,000	Soil and crop suitability
14	Chipangali	100	Dalal-Clayton	1983	Y	Y	N	R	28,250	1:30,000	Suitability for state farm
15	Evan Farm	127	Silungwe & Kalima	1984	Y	Y	N	SD	1600	1:30,000	Soil distribution
16	Masumba Kakumbi	182	Munyenyembe	1988	Y	Y	N	SD	5082	1:50,000	Land capability for veg. farming
17	Chikwangala Farms	188	Banda	1988	Y	Y	N	SD	9870	1:30,000	Soil suitability for irrigation and rain-fed crop production
18	Nakambala Farm 10/3666	220	Msoni & Mulenga	1992	Y	Y	N	D	960	1:30,000	Determine soil types and distribution

* Present in the ISRIC repository online or not?
** D: detailed, SD semi-detailed, pD partly detailed, R reconnaissance (as described in the title).
1 Airphotos at 1:10,280 used in the field. Boundaries were transferred to a map, scale not specified.

Table 1b
Legacy soil surveys identified in Eastern and Southern Provinces of Zambia.

	Short name	Soil Survey report No.	Number of soil legend units	Soil legend unit type	Land capability classes (LC)	Soil classification
1	Upper Kaleya	4a	5	Simple	LC class identified for each soil unit	Zambian Series and phases defined on texture and general classes e.g. "shallow and sloping sandy loams"
2	Heales Estate	5a	13	Simple	LC class identified for each soil unit	Zambian Series* ("phases" with different capability distinguished) and general e.g. "sandy loams and loamy sands"
3	Nakambala 2nd Ext.	10	11	Simple'	LC class identified for each soil unit	Zambian Series* with texture and drainage classification
4	Sasare Block	12	15	Simple	LC class and CS class identified for each soil unit.	Zambian Series*, with some depth and textural phases, and general e.g. ("rough broken land")
5	Nakambala 3rd Ext.	13	13	Simple	LC classes identified for MU. Crop suitability assessed for each MU	Locally defined soil classes based on texture, slope, drainage and soil depth
6	Pemba Village	16	6	Simple	LC class for each unit	Locally defined soil classes based on texture, slope and soil depth
7	Mochipapa	20	15	Simple	LC classes identified for MU (not 1:1). Crop suitability assessed for each MU	Zambian Series*, with some depth phases and different 'uncategorized' dambo soils.
8	Nakambala 4th extension	25	14	Simple	LC, CS and irrigability identified for each unit	Zambian Series*, with texture, depth, slope differentiation.
9	Masumba	27	11	Simple	LC classes and CS for each unit	Zambian Series* with texture and drainage classification
10	Magoye	46	11	Simple	LC classes and CS for each unit	Locally defined based on texture, drainage and slope, with Zambian Soils series* names identified for some.
11	Nakambala 5th Ext.	48	15	Simple	LC and Irrigability identified for each unit	Locally-defined soil classes based on depth, drainage status and texture grouped by landscape position
12	Sikaleta-Nanzhila	63	14	Simple	LC classes identified for each unit.	Locally-defined soil classes within parent material units defined on depth, drainage status, colour and texture.
13	Zambezi Ranching	72	26	Simple	Land capability legend	Map units are land-capability, but a distinct description in terms of soil horizons is given for each. Phases distinguished on, e.g. slope or other limitations
14	Chipangali	100	14	Simple	LC classes with irrigability	Locally defined soil classes, with corresponding Zambian series*, USDA and FAO classification listed in the memoir
15	Evan Farm	127	6	Simple	LS for each unit identified	Locally determined on basis of depth, drainage, colour and slope
16	Masumba Kakumbi	182	12	Simple	LC class and CS class identified for each soil unit	Zambian Series* and phases defined on texture and general classes.
17	Chikwangala Farms	188	9	Simple	LC and CS. Separate irrigability map developed.	Locally determined
18	Nakambala Farm 10/3666	220	8	Simple	LC	Locally determined based on texture and drainage. Zambian series* identified.

*At least some of these Series listed by Soil Correlation Section (1987). SSU Handbook No. 1.

3.2. *Trapnell's traverse records*

The traverse records of Trapnell (Smith and Trapnell, 2002) contain a lot of information on soil, vegetation, and farming systems. Examples of this information are presented in Tables 2–4. We show the locations of recorded sample points on two of the traverse sections detailed in Table 2 in Fig. 3. As an ecologist, Trapnell's map legend units were based primarily on vegetation and physiography, but some generalizations about the soils in these units are possible (see Table 3), and Trapnell advocated vegetation-based approaches for small-scale survey of soil, as seen in his contributions to discussions held by the East African soil chemists regarding soil survey at regional scale (Trapnell, 1935). The traverse records therefore record soil information, primarily on texture, soil colour, and in some cases soil constraints on land use and agriculture such as erosion and suitability for agricultural production and how soils were related to the vegetation and topographical position (Table 2). For example, in the traverse section labelled Matambazi stream to Nyimba resthouse we find descriptions of contrasting soil colour and texture between the plateau, upper valleys and dambos (seasonal water courses), which also have characteristic assemblages of vegetation. It must, however, be noted that Trapnell did not record soil information using any standard protocol nor are there records of descriptions of sequences of horizons in soil profiles as might be expected in a modern soil survey memoir. Furthermore, soil texture is not related to a specified texture triangle; and Trapnell's descriptions of soil colour cannot be related to modern systems. Trapnell describes soil colour using terms including 'red-chocolate', 'chocolate', 'pinkish brown' (Table 2, Matambazi stream to Nyimba resthouse section), 'pink-grey' (Table 2, Kalomo to Ibula section) and 'orange brown' (Table 4b, Nyanje's). At the time the description of soil colour was not standardized. Terms such as 'orange' and 'chocolate' appeared in colour triangle schemes such as that of Zakharov (Joffe, 1949), but Joffe (1949) describes the problem of colour description as 'unsettled', referencing reports from 1920 to 1931 of the American Soil Survey Association, which had a 'Committee on Soil Color Standards'. According to Landa (2004) the Munsell colour system did not come into common use by soil surveyors in the United States until about 1950. There was therefore not a generally-approved system for the description of soil colour during the period of Trapnell's field work in Zambia from 1932 to 1942.

The farming practices of the local people were recorded by Trapnell (Table 4), and these are very detailed accounts of how agriculture was conducted at the time. Furthermore, they are not merely 'snapshots' of what was in situ at the time of Trapnell's visit to a site, but reflect discussions with farmers about shifting cultivation practices. See, for example, the account in Table 4a of practices at Lusinga's, where different cropping practices were followed in five successive seasons, including intercropping of diverse crops including pumpkins, cucumbers and water melons along with maize in an intimate mixture across contrasting microsites in the first two seasons and monocropping of the less-demanding sorghum in years three to five. It was noted that the same site would then not be planted until at least six years of fallow. In addition, Trapnell records adaptive practices to manage drought risk. Again at Lusinga's, land was prepared by forming mounds or ridges of grass between maize plants, which would be planted with sweet potato if rain

Table 1c
List of legacy soil surveys listed as implemented by NORAD (1981) but could not be traced.

	Short name	Soil Survey report No.	Lead author	Year	Survey type	Province
1	Nakambala 1st Ext.	1a	Mumba	1971	D	Southern
2	Mbaya Musuma	3a	Mumba	1971	D	Eastern
3	Msekera	19	Commissaris	1975	D	Eastern
4	Kalichero	23	Commissaris	1974	R	Eastern
5	Chinjara Ranch	29	Commissaris	1975	SD	Eastern
6	Chipata North	30	Commissaris	1975	SD	Eastern
7	Dunelm Estates	31	Commissaris	1975	SD	Eastern
8	Mtirizi	91	Dalal-Clayton	1982	R	Eastern
9	Lusito Settlement	Unknown	Unknown	Unknown	Unknown	Southern
10	Batoka Ranch	Unknown	Unknown	Unknown	Unknown	Southern
11	Kayuni Ranch	Unknown	Unknown	Unknown	Unknown	Southern
12	Naluama Ranch	Unknown	Unknown	Unknown	Unknown	Southern
13	Harmony Ranch	Unknown	Unknown	Unknown	Unknown	Southern
14	Zimba Hills	Unknown	Unknown	Unknown	Unknown	Southern
15	Lundwe's farm	Unknown	Unknown	Unknown	Unknown	Southern
16	Kabuyu	Unknown	Unknown	Unknown	Unknown	Southern
17	Mwami farms	Unknown	Unknown	Unknown	Unknown	Eastern
18	Ngwata Estates	Unknown	Unknown	Unknown	Unknown	Eastern
19	Lumesi	Unknown	Unknown	Unknown	Unknown	Eastern
20	Mtonga farm	Unknown	Unknown	Unknown	Unknown	Eastern
21	Gonda Barracks	Unknown	Unknown	Unknown	Unknown	Eastern
22	Farm D/27	Unknown	Unknown	Unknown	Unknown	Eastern
23	Kapoya farm	Unknown	Unknown	Unknown	Unknown	Eastern
24	Luambwa Rural RC	Unknown	Unknown	Unknown	Unknown	Eastern
25	Chanje area	Unknown	Unknown	Unknown	Unknown	Eastern
26	Chasefa area	Unknown	Unknown	Unknown	Unknown	Eastern
27	Magodi area	Unknown	Unknown	Unknown	Unknown	Eastern
28	Chitandika	Unknown	Unknown	Unknown	Unknown	Eastern
29	Nkungwa settlement scheme	Unknown	Unknown	Unknown	Unknown	Southern
30	Nyanmphande Extension	Unknown	Unknown	Unknown	Unknown	Eastern
31	Simonga Wheat Scheme	Unknown	Unknown	Unknown	Unknown	Southern
32	Mugoto ranch	Unknown	Unknown	Unknown	Unknown	Southern
33	Kayuni ranch	Unknown	Unknown	Unknown	Unknown	Southern
34	Chama Rice Scheme	Unknown	Unknown	Unknown	Unknown	Eastern*
35	Chikoli state ranch	Unknown	Unknown	Unknown	Unknown	Southern
36	Kalomo FTC	Unknown	Unknown	Unknown	Unknown	Southern
37	Siachitema area	Unknown	Unknown	Unknown	Unknown	Southern
38	Kalomo PFA	Unknown	Unknown	Unknown	Unknown	Southern

*The province has changed after introduction of Muchinga province in 2011.

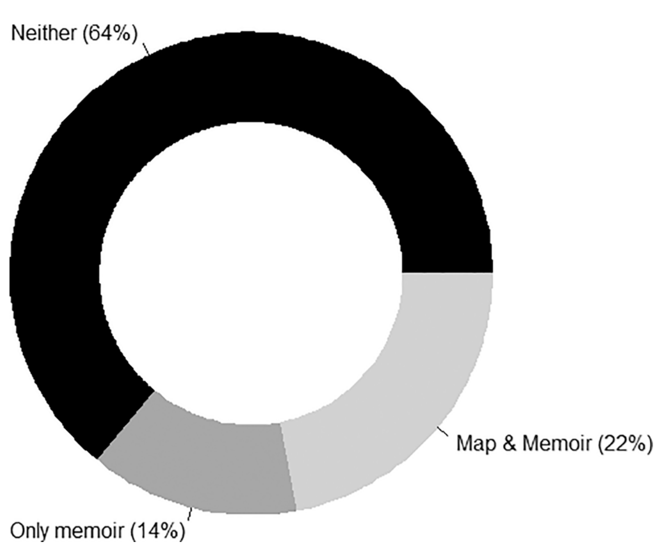

Fig. 2. Summary of the outputs recovered from the inventory of legacy soil information in Southern and Eastern provinces of Zambia.

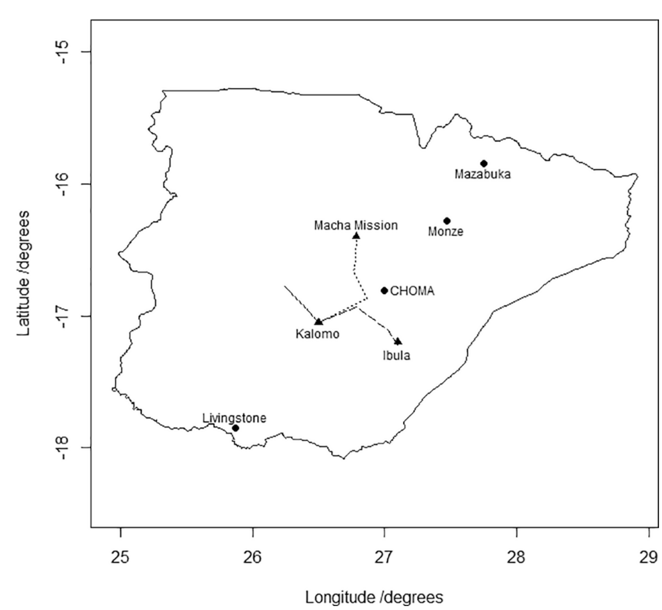

Fig. 3. Southern Province in Zambia. Choma is the provincial capital, other major towns are shown along with Kalomo from which two traverse sections given in Table 2 started. The dotted line is the Kalomo to Macha traverse (which starts with a section heading north west, and then returns, via Kalomo, to locations further east and north. The dashed line is the Kalomo to Ibula traverse.

followed within two weeks, or left as a mulch if not. Trapnell also took considerable interest in the site or soil-selection practices of the farmers he visited. Some examples are recorded in Table 4b. The primary guidance to suitable sites for cultivation were ecological. For example, at

Table 2
Examples of soil information extracted from Trapnell's traverse records. Note that botanical names given are those used in Trapnell's original notes. A table of synonymy giving modern equivalents, and based on a larger Table provided by Smith and Trapnell (2002), is in the Supplementary material (Table S1).

Traverse section details	Key information summary
Mwape's to Chikowa (p 449–453, Vol 2)	This section starts in lower valley alluvium soil south of Petauke (L3), and passes through sections of marginal upper valley dominated with *Brachystegia* woodlands (U1) into upper valley dominated with *Pterocarpus–Combretum* vegetation (U2) ends in Petauke on Escarpment hill soils in *Brachystegia-Isoberlinia* vegetation (E1). The soils are generally coarse sandy loam and reddish brown in the marginal upper valley (U1), dark brown sandy loam in *Pterocarpus–Combretum* dominated upper valleys (U2). In the higher elevation escarpment (E1) soil colour ranges from dark/chocolate brown to reddish brown, with sandy loam to sandy texture.
Matambazi stream to Nyimba resthouse (p532–547, V2)	This section starts in the plateau with *Brachystegia–Isoberlinia vegetation* (P6) on the southeast of Petauke, crosses through some sections of the central *Isoberlinia–Brachystegia vegetation* (P5) and then into the upper valley *Combretum–Afrormosia* and *Pterocarpus-combretum* vegetation (U2) with some pockets of the upper valley dominated with *Brachystegia hockii* and related woodland (U1). Transitional vegetation/soil is observed as you cross back and forth between the plateau and the upper valleys and, a number of dambos and streams are crossed all along the section. The soil colour in the plateaus is generally brown with some grey, grey-brown and pale/pinkish/orange-brown soils, while the texture is overwhelmingly sandy loam with a few loams. In the upper valley the soil colour is generally darker than that observed in the plateau with recorded colours including pinkish brown, brownish orange, grey and dark brown and chocolate. The soil texture had a wider range in the upper valley with loam, fine sandy loam and sandy loam similar to the plateau, but also with coarser soils such as coarse sandy loam, sandy, gravelly soils. The dambos are generally dark coloured with grey, red-chocolate, chocolate, dark/very dark grey to black soil soils recorded, but become lighter, e.g. pinkish brown, when cultivated. The texture in the dambos ranged from clay to coarse sandy soil, but mostly were loam to sandy loam.
Kalomo to Macha (p 530–533, Vol 1). See also Fig. 3.	Although this section starts in Watershed grassland (S4) in Kalomo and ends in upper valley soils (U2) in Macha, most of the soil descriptions fall within the plateau (P7) with *Brachystegia–Isoberlinia* vegetation with a number of dambos along the section. The dambos are associated with *Hyparrhenia ruprechtii and Hibiscus spp*, *Acacia campylacantha* with *Thespesia* mostly on the dambo head/edges. *Burkea, Terminalia, Vangueriopsis and Isoberlinia–Uapaca* vegetation during regeneration to probably *Brachystegia hockii* finally. Cap cultivation near *Brachystegia hockii*, cultivation also on dambo edges. Cultivation also on fertile valley slopes in *Brachystegia hockii* vegetation. Soils Properties: Soil texture varying from very sandy to sandy on the plateau and sandy loam close to dambos and towards the upper valley close to Macha. Soil colour generally reddish to red-brown on the plateau and chocolate in or near dambo and dark brown towards the upper valley soils of Macha.
Kalomo to Ibula (p 585–586, Vol 1). See also Fig. 3.	This section starts in a watershed grassland (S4) in Kalomo dominated by *Hyperrhenia* vegetation and then onto plateau soil dominated by *Isoberlinia globiflora–Brachystegia* woods (P7) and ends on Escarpment hill soils with *Isoberlinia globiflora–Brachystegia* (E2). All along the section there are *Trichopteryx simplex* dambos. Soils observed include sand schist soil on transitional fringes onto hills, reddish sandy loam, pink-grey immature sand or sandy loam in *Hyperrhenia ruprechtii* dambo edge, black humic loam, peaty loam or clay loam at the edge of the hills near Muchenge stream. Summer gardens in drained edge of portion of the stream with humic sandy loam and on immature sandy colluvium from the hills. Summer gardens also on upper slope from hills in *Brachystegia hockii–Isoberlinia–Uapaca* vegetation and winter peaty gardens on the valley and edge of the dambo across the stream and on peat soil with or without some clay in *Pennisetum* grass.

Nyanje's (Table 4b) Trapnell was told that land where *Isoberlinia globiflora* (now *Julbernardia globiflora*) grew was of poor fertility, only able to support two years cropping, in contrast to land where this tree was found in association with *Brachystegia hockii* (now *B. spiciformis*). Soil was also recognized as a factor in site selection, the fertile *I. globiflora – B. hockii* association was associated with fine-grained loam soil, compact and of orange-brown colour, and dambo soils under *Hyparrhenia* grass and *Acacia woodii* (now *A. sieberiana* var *woodii*) were favoured for maize production at Mantanyani's.

While a lot of valuable information is presented in the Trapnell records, some challenges were noted in the process of extracting this information. The first is the inconsistency in the use of shorthand notation on cropping systems, especially when distinguishing between rotations and inter/mixed cropping. A hyphen and forward slash were each used to mean a rotation and inter/mixed cropping in different sections of the notes. For example, at a place called Chifusa's (p531-532 vol 1) Trapnell reports the most common cropping sequence as; finger millet alone or groundnuts/maize-Sorghum-bulrush millet. Here the forward slash was interpreted to mean mixed or inter-cropping while the hyphen to mean rotations (groundnuts and maize in year 1, followed by Sorghum and then followed bulrush millet in years 2 and 3). However, at a place called Bombwe (p577-581 vol 1) the cropping sequence is recorded as; Bulrush millet/bulrush millet/sorghum, which suggests that the forward slash here is referring to a rotation as opposed to mixed or inter-cropping.

Second, Trapnell's descriptions of cropping systems was based on interviews with locals in the locations he visited. In some cases, the recorded accounts of the types of crops and the management practices differed from different people within the same area. While this makes the traverse records difficult to follow in such instances, it could however be an indication of the variations in the practices or experiences among different households/people within the same location/village. This fine-grained variation in practice is interesting, particularly given Trapnell's systematizing approach to farming practices evidenced in the generalized descriptions of regional farming systems presented in the reports on Central and Western and Northeastern Zambia (Trapnell and Clothier, 1996; Trapnell, 1996).

Third, to extract the vegetation-soil units from the maps, the locations of some of the places Trapnell recorded had to be inferred as described in section 2.2.2. However, a number of them could not be located on the map, sometimes even the given coordinates seemed not to match with the descriptions in the traverse records or in relation to other nearby points. This is not surprising. The locations of particular communities, particularly under shifting cultivation, were not necessarily stable over time, and this challenge has been noticed elsewhere in Zambia, for example by Moore and Vaughan (1994) who attempted to

Table 3
Trapnell's Soil-vegetation map units and their characteristics (Trapnell et al., 1947; Smith and Trapnell, 2002; Trapnell and Clothier, 1996). Note that botanical names given are those used in Trapnell's original notes. A table of synonymy giving modern equivalents, and based on a larger Table provided by Smith and Trapnell (2002), is in the Supplementary material (Table S1).

Soil Unit	Vegetation[†]	Topographical position	Texture	Colour	Soil suitability	Other characteristic features
Plateau soils (P)	*Brachystegia–Isoberlinia* woodland of varying types	Plateau, 4000ft altitude	Surface: Light (sandy-loam) textured Subsoil: Clay-sand	Surface: Buff toned to light pinkish-brown Subsoil: raw ochreous or orange-toned	Generally unproductive, low fertility	Iron nodule horizon due to impeded soil drainage. Acidic and base-deficient
Kalahari Sands (K)	*Burkea–Copaifera-Baikiea* forest, Scrub grasslands, *Acacia-Combretum* and allied vegetation, *Commiphora–Combretum* vegetation, *Isoberlinia–Brachystegia* woodlands of varying types		Pure loose coarse-grained sand. some clay proportions in subsoil	Whitish but grey (if surface discoloured with organic matter or ash), golden or reddish when stained with iron oxide	Low fertility/productivity-chemically poor	
Upper Valley soils (U)	*Brachystegia hockii* woodlands, *Combretum–Afrormosia* and *Pterocarpus–Combretum* vegetation, *Acacia–Combretum* and allied vegetation	Lower lying regions than plateau soils, gently rolling areas with free drainage	Light fine-grained sandy loam to heavier friable loam.	Pinkish-brown or cocoa-coloured to chocolate-brown and dark brown Brownish-red to chocolate-red	Richer and more fertile than plateau soils (higher base saturation, P and N content)	More fertile than plateau, Associated with limestone and mica schist
Lower Valley Soils (L)	*Brachystegia–Isoberlina* woodlands of varying types, *Copaifera mopane* woodlands, *Commiphora–Combretum* vegetation, *Acacia–Combretum* and allied vegetation	Lower valley floor	Sand to clay-sand with fine grained loam Clay near riverbeds	Chestnut to Light Brown	Generally very fertile. However, those in mopane (*Copaifera mopane*) bush agriculturally "useless"/ problematic (largely due to being heavy and wet in rain season, erosive tendency, poor grass growth)-	Lime accumulating, formed from colluvial or alluvial sedimentary Karroo rocks Very fertile
Grey and Black Swamp soils	*Erythrophloeum–Pterocarpus* and Chipya vegetation, Bush-group vegetation	Flood plains and seasonally swampy grasslands	Sandy, clay-sand mixture clay	Grey or brownish-grey (dambo) Buff Black	Leached or degraded and generally of low fertility	
Escarpment Hill soils (E)	*Brachystegia/Isoberlinia* vegetation of varying types	Stony steep slopes of escarpments				Shallow No clear profile characters Immature

examine changes in landuse practice in Northern Province of Zambia by comparing modern practices with the earlier observations of Richards (1939). The inference of a described location's vegetation-soil unit depended on the type of vegetation mentioned as well as the relation (e.g. distance from) with a location with known coordinates. However, it was not always possible to pick out one unit due to some similarities among some of the units. For example, Trapnell's "Central *Isoberlinia paniculata–Brachystegia* woodlands on plateau soils" (P5) and "Eastern *Brachystegia-Isoberlinia* woodlands on plateau soils" (P6) were both reported in the Eastern province, and they contain the same types of vegetation. Another example is the "*Commiphora–Combretum–Pterocarpus* thicket or forest on lower valley Karroo Sands" (L2) and the "*Acacia–Combretum* and allied vegetation on lower valley and other alluvium" (L3) units –these are mostly the same or very similar. In the latter case, the mention of *Commiphora fischeri* was key for the identification of the L2 unit.

As a final comment, we note that the soil-vegetation survey of Trapnell et al (1947) and the associated traverse records are an unusually detailed record of past field work. However, their potential which we have shown here should motivate studies of the records of other field workers who undertook pioneering work in settings where soil information is now required. For example, Milne (1947) published a detailed account of soil field work in Tanzania, and this would repay further study along with the archive of his diaries, memoranda and correspondence from the period which is held in the library of Rhodes House in Oxford (Oxford, Bodleian Libraries [MSS.Brit.Emp.s.457]). These have already been examined in a historical investigation of the origins of the catena concept (Borden et al, 2020).

3.3. *Assessment of large-scale legacy soil maps*

3.3.1. *Survey scale, purpose and legend.*

Of the large-scale surveys identified the published scale of 15 could be recorded unambiguously. Three were at scale ratios larger than 1:10,000 (1:5,000 to 1:5,700); two were at 1:10,000 and one at 1:11,000; Seven were at 1:30,000 and two at 1:50,000. Twenty six surveys were identified in their titles as Detailed (13), Semi-Detailed (8) or Reconnaissance (5, one as Reconnaissance and part Detailed). The cartographic scales were not strictly consistent with these titles, ranging from 1:5,000 to 1:30,000 for the surveys entitled Detailed, 1:30,00 to 1:50,000 for Semi-Detailed (for most of these the cartographic scale of the map-sheet was not known) and 1:30,000 to 1:50,000 for Reconnaissance.

Most of the large-scale surveys reported here used Zambian Soil Series to define the legend units, sometimes in combination with phases defined in terms of depth or textural variations, and with general units such as 'uncategorized dambo soils'. Some used soil classes defined locally in terms of texture, slope or soil depth, and others used a combination of such local classes and Zambian Soil Series. In one case the legend units were defined in terms of land capability only, and in another the locally-defined classes were related to USDA and FAO-UNESCO soil classes. In none of the observed maps were there map units where series or locally-defined classes were combined into complex units.

Table 4a
Examples of information on farming systems/practices extracted from Trapnell's traverse records. Note that botanical names given are those used in Trapnell's original notes. A table of synonymy giving modern equivalents, and based on a larger Table provided by Smith and Trapnell (2002), is in the Supplementary material (Table S1).

Traverse section and name	Cropping system information[†]
Lusinga's (Serenje–Petauke–Mkushi–Kapiri Mposhi Traverse, p451 Vol 2)	• Cut trees and grass heaped (**Milala, Vikuse**) and then burnt. Maize is planted with some pumpkins and cucumbers (different varieties; **Manguta, Uvimbi, Kasongo**) on the burnt portions, while cowpeas on the un-burnt portions (maize does not do well on un-burnt portions). Planting done in November just before the rains. Grass between plants hoed and piled and made into mounds/ridges (**Mbunde**) and plant sweet potatoes if it rains within 2 weeks, left as mulch if it is dry (no rains within 2 weeks). In second year, dry weeds from previous season are burnt. Maize grown on the newly burnt sites and between the old mounds with pumpkins, cucumbers and water melons (**Mavwembe**). Maize and Sorghum planted separately on old maize mounds, but only sorghum if "little rain". Maize generally does poorly in second year while sorghum does well. Green gram (**Kankoma**) grown in any of the sites. In 3rd-5th years, only sorghum is grown. Grass/plant residue not burnt but used as mulch (**Chipalapala**). By 5th year productivity is very low and will leave to new site and may return after at least 6 years. Groundnuts, and ground beans on separate garden, planted in separate sites for 1–2 years and then followed by maize if soil is good or sorghum if soil is not good. Little bulrush millet in grown in the area while rice is grown in swampy sites.
Chewa gardens (Chipata-Katete-Petauke Traverse, p521-522, Vol 2)	• 1st year: Acacia trees cut and piled with grass heaps (**Vikuse**), then burnt and covered with soil into mounds, after which maize planted on the mounds and between the mounds before the rains. Pumpkins (**Mumbu**), beans (**Kayera**) and cowpeas (**Nyemba**) planted together with maize on the burnt heaps. Cowpeas and beans only planted during the rain season (around December), while maize and pumpkins planted before the rains start. Maize is planted alone on the un-burnt places between the burnt heaps. The burnt and un-burnt heaps (**Vikuse**) are later broken down/shifted away to make new ones, with only a small heap left around the maize plant. Groundnuts (**Siaba**) or beans then planted on the new heaps (**Vikuse**) 2nd year: Maize planted on side of or between the groundnut mounds, while the mounds were maize was are again broken and drawn away to make news on which groundnuts are planted. 3rd year onwards maize and grounds, and may make new garden extension. Generally gardens used for 3–9 years for maize cultivation, with groundnuts only grown for 2–3 years on the same land. Cultivation of older land: groundnuts planted on flat land by deep hoeling. Maize residues and weeds are piled and burnt between the mounds, then plant groundnuts(?) on the side/between mounds. Some plant residues heaped between old maize plants and left as manure (to decompose?), without planting anything.
Nangoma (Southern and Central Province Traverse, p542-543, Vol 1)	• Cultivation in deep red to orange valley soils. Sweet potatoes-cassava or maize-sorghum rotations (maize grown for 4 consecutive years of the rotations). After maize move to new site down the dambo while land is fallowed for 3–4 years and returned to when bush (grass) is tall. Maize –sorghum planted in new site. Tobacco gardens on anthills and maize-pumpkin ash gardens (burnt sites) in bush-*Brachystegia paniculata* vegetation Trees/bush cut in June-July, piled around an anthill, left to dry and then burnt in August-September. Left to cool for a month (October), and then planting done in November. Early maturing crops, maize and pumpkins or finger millet and pumpkins are planted round the edge of the burn anthill garden (**Chishita**). **Chishita** later extended into bigger field (**Muunda**). In the larger cleared garden (**Muunda**), finger millet or maize grown in first year and then pumpkin if soil is good or maize only; or maize with/without finger millet in both years. Logged sites around the burnt area made into Maize-sorghum or sorghum-pumpkin fields. Alternatively clear trees at new site around the anthill and plant maize-sorghum-pumpkins rotations (three years total) and then sweet potatoes before abandoning site for good.

[†] bold words in parentheses are local/indigenous names of the crops or systems.

Table 4b
Examples of soil selection principles observed by Trapnell. Note that botanical names given are those used in Trapnell's original notes. A table of synonymy giving modern equivalents, and based on a larger Table provided by Smith and Trapnell (2002), is in the Supplementary material (Table S1).

Traverse section details	Land selection principles
Mantanyani's (Southern and Central Province Traverse, p566 Vol 1)	• Village gardens were located in *Hyparrhenia filipendula* or *Hyparrhenia ruprechtii* with *Brachystegia hockii* and here groundnuts or maize intercropped with bulrush millet would be planted. The main field would be chosen in the vicinity of dambo sites dominated by *Hyparrhenia filipendula and Acacia wodii.* Maize would be planted here in early years and later sorghum. Land dominated with *Brachystegia flagristipulata* was regarded as less fertile and it would be planted with finger millet and used for no more than 3 years.
Nyanje's (Chipata-Katete-Petauke Traverse, p530, Vol 2)	• The best land is indicated by the presence of *Hyparrhenia* grass with *Acacia campylacantha* tree cover. This land would be cultivated for up to 8 years then fallowed for 4 years or "until grass is tall" and re-cultivated for 4–5 years Land is indicated as good by the presence of *Afromorsia* vegetation with *Acacia campylacantha* or land co-dominated by *Brachystegia hockii* and *Isoberlinia globiflora* on fine grained compact loam orange brown soil. This would be cultivated for 4–5 years, fallowed for 4–5 years and re-cultivated for a further 2–3 years.. Land under *Isoberlinia globiflora* only is regarded as poor. It is said to get exhausted within 2 years of cultivation.

Table 5a
Assessment of the boundary density (D), area size delineation (ASD) and index of minimum reduction (IMR) of the legacy soil maps.

Survey	Map scale	D (cm/cm^2) ± SE	ASD (cm^2)	IMR
1. Upper Kaleya	1:10,000	0.64 ± 0.06	14.8	6.1
11. Nakambala 5th Extension	1:10,000	0.34 ± 0.03	22.2	7.4
12. Sikaleta-Nanzhila	1:50,000	1.15 ± 0.12	5.3	3.6
13. Zambezi Ranching	1:30,000	0.87 ± 0.09	4.5	3.3
14. Chipangali	1:30,000	1.13 ± 0.11	8.4	4.6
16. Masumba Kakumbi 1	1:50,000	0.91 ± 0.09	7.9	4.4
16. Masumba Kakumbi 2	1:50,000	0.96 ± 0.09	8.4	4.6
Optimal value (Forbes et al)				2.0

Table 5b
Relationship between map scale and map intricacies.

Survey	Map scale	Map Intricacy (intersections/km)	
		Estimated value	Predicted value (Bie and Beckett, 1971)
1. Upper Kaleya	1:10,000	4.10	5.01
11. Nakambala 5th Extension	1:10,000	2.15	5.01
12. Sikaleta-Nanzhila	1:50,000	1.47	1.22
13. Zambezi Ranching	1:30,000	2.41	1.91
14. Chipangali	1:30,000	1.92	1.91
16. Masumba Kakumbi 1	1:50,000	1.10	1.22
16. Masumba Kakumbi 2	1:50,000	1.22	1.22

Table 6
Number and institutional affiliations of participants who attended the workshop.

Type of institution	Number (%)
Government (extension and research)	6 (42.8)
NGO (national)	1(7.1)
NGO (international)	1(7.1)
Academic	3(21.4)
Private sector: large-scale commercial farming	1(7.1)
Private sector: agricultural advice/inputs	1(7.1)
Private sector: R&D	1(7.1)

Table 7
Summary of the views of participants on the use of legacy and contemporary soil information.

Question	Responses given
What aspects of the legacy soil information provided might be of value now?	Soil properties provide baseline data useful to see what has changed; can still be used for planning. Investigation of the relationship between field texture determination and lab determined textures. The relationship between vegetation types and soil characteristics. Directly as soil information for properties unlikely to change (e.g. texture).
Can you give specific examples of how the legacy soil information might be used by you	In assessing landuse suitability. Establishing historical trends and relationships between vegetation types, soil types and land suitability. As an input to support more detailed survey, e.g. by digital soil mapping. Assessing how soils have changed. Historical information on cropping systems over different soils may help with development and recommendation of new 'ecological' systems
What do you think are the main reasons why the legacy soil information might be of limited or no use to you or your organization (or your equivalents at that location)?	Not readily available; information or classification too old and too much concentration on geology and vegetation rather than soils; lack of awareness on its availability and benefits; less detailed and too general. The focus on agricultural uses of soil reduces its value to users interested in environmental aspects such as pollution. Do not account for changes in the landscape. Some soil properties (e.g. pH) particularly prone to change. Limited scale of the surveys and spatial coverage.
How might the contemporary soil information be of use now to you or to others with a similar role	Determining soil suitability for agriculture production/crop recommendations; planning; estimation of ecosystem services; helps understand changes in soil; decision making and advisory at farm level
What do you think are the main limitations on the value of the contemporary soil information for you or for others with a similar role?	Difference in focus and intended use; too technical and not easy to understand for a layperson; not always very specific; not very detailed for use at farm level and lacks "exact soil quality" and recommendation for immediate use; accuracy limitations; The impact of any soil property on performance of any given land use type is hard to establish.
Are there aspects of the legacy soil information (e.g. the content, the structure) and the survey methods used to produce it which might be usefully incorporated into modern approaches to collect and present soil information?	The land capability and land suitability classification structures. Classifications of the soil which reflect factors which are relevant to local farmers. The collection of information on land use.

Table 8
Summary of participants' views on historical farming systems information.

Question	Response
What do you think were the main agronomic challenges or limitations which the farmers practicing these systems faced when Trapnell recorded them?	Decline in productivity; low rainfall/drought; poor fertility/nutrient supply; weeds pressure; soil acidity; soil erosion; nutrient leaching
Can you name aspects of the system which could be regarded as adaptations to these challenges?	Use of legumes; fallowing; slash/cut and burning vegetation; crop rotations and intercropping; shifting cultivation; careful soil selection; Ridges
Are there any other features of the historical systems which you might still see practiced today? If so, then why have they been retained?	Use of *Julbernardia* trees has been retained to get the benefit of nitrogen produced and the amount of organic matter obtained from the leaves shed; shifting cultivation still practiced due to lack of financial resources to buy fertilizers and other inputs

3.3.2. *Map texture and intricacy*

The boundary density, ASD and IMR for seven map-sheets of scales 1:10,000, 1:30,000 or 1:50,000 are shown in Table 5a. The boundary density ranged from 0.34 to 1.15. The IMR for the maps evaluated ranged from 3.3 to 7.4 which is much higher than the recommended optimal value of 2.0 (Forbes et al., 1987). This means that the legacy maps are legible but their scales could be reduced substantially without losing the legibility of the map units (Rasaei et al., 2020). The scale of a soil map is typically interpreted as evidence of the level of detail which it represents, with small scale maps inevitably more generalized than those of larger scale. This is seen in typical definitions of terms for surveys, and their suitability for different purposes. For example, Young (1976) calls surveys at scales larger that 1:10,000 'intensive', and suitable for management purposes. Detailed surveys, suitable for development planning, are typically at scales of 1: 25,000 to 1:10,000 and are suitable for development planning, and may be useful for feasibility studies. Semi-detailed surveys are typically at scales of 1:100,000 to 1:25,000, suitable for the siting of projects or feasibility studies, and reconnaissance surveys at scales less than 1:100,000 are suitable for resource inventory. We have already noted that the titles given to surveys in this legacy set, and their scales, are not consistent with this standard terminology. It is interesting that the IMR values suggest that the map texture is not entirely consistent with the published scale, with larger delineations than would be expected. Interestingly the largest delineations and smallest boundary densities are on maps at 1:10,000 described as Detailed, which the IMR suggest could be rescaled to a scale in Young's (1976) semi-detailed range. Both these surveys were to support land capability assessments, in one case for small holder production, and in the second for rain-fed or irrigated production. Such use for feasibility study is consistent with Young's (1976) description of semi-detailed surveys. The smallest delineations are on the survey for Zambezi Ranching (Number 13 on Table 1a), this survey, published at 1:30,000, is described as a combination of reconnaissance and partly detailed, carried out for crop suitability studies. The densest boundaries are on the Sikaleta-Nanzhila sheet, described as a reconnaissance survey (1:50,000), but the purpose was general land capability assessment. The IMR might suggest possible adjustments of these two surveys to scales in the reconnaissance range of Young (1976).

Of course, the scales, boundary densities and ASD values and their relations are not prescriptive, and variations may reflect differences in the complexity of soil patterns in different landscapes. That said, these results do suggest that the publication scale of these legacy surveys should be interpreted with caution relative to usual international expectations of levels of detail on the soil map.

Consistent with the observations above, the measured map intricacies for maps of larger scale ratio were smaller than the values predicted from the map scale with the regression due to Bie and Beckett (1971) (Fig. 4a, Table 5b), although the results were consistent with Bie and Beckett (1971) for the smaller-scale maps.

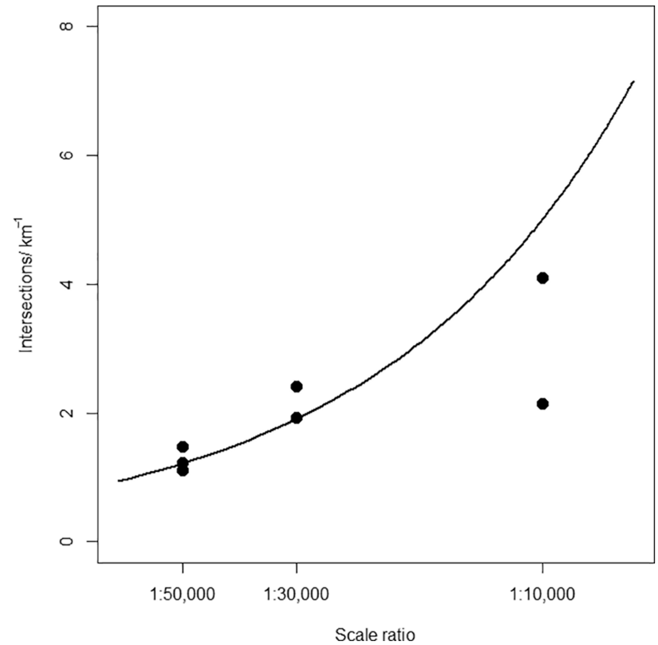

Fig. 4a. Relationship between map scale and intricacy of the mapped boundaries. The solid symbols show the intricacy of mapped boundaries for 7 legacy maps with different scale ratios, the solid line shows the predicted intricacy as a function of scale from the equation from Bie and Beckett (1971).

Fig. 4b shows the relationship between the survey effort and the map scale for the four surveys where the field effort could be calculated. There was a general increase in the survey effort with increase in the map scale. This again is in agreement with Bie and Beckett (1971). However, at the largest scales (around 1:5,000), the survey effort in the evaluated legacy soil surveys was much lower than what is predicted using the equation developed by Bie and Beckett (1971). This is too

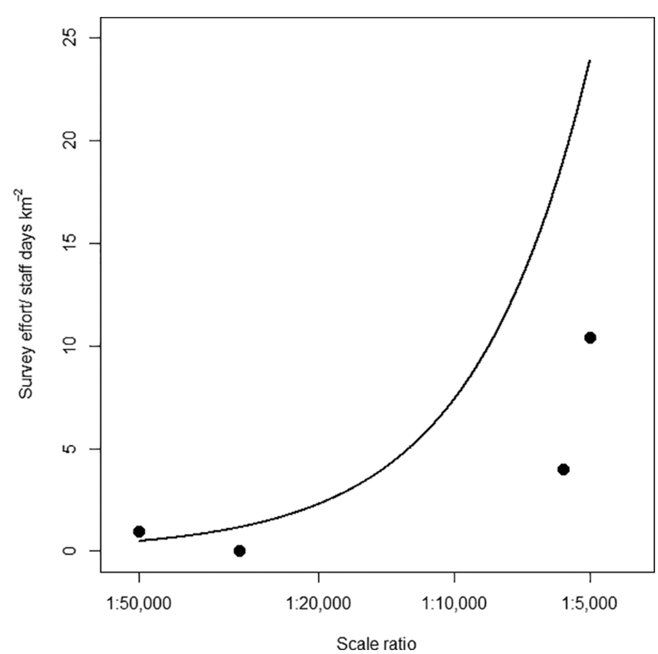

Fig. 4b. Relationship between map scale and survey effort. The solid symbols show the survey effort recorded for 4 legacy maps with different scale ratios, the solid line shows the predicted effort as a function of scale from the equation from Bie and Beckett (1971).

small a data set to support a general conclusion, and account should be taken of differences between the soil landscapes of Zambia, and Australia where Bie and Beckett (1971) collected their data, but it may suggest differences between the understanding and practice of intensive soil survey in the two locations.

Finally, we note that legacy large-scale soil surveys are not unique to Zambia. Young (2017) describes how soil survey activities continues post-independence in many countries in Africa and Asia. For example, the Government of Malawi published a catalogue of 18 surveys produced in 1971 – 1972 (Kingston et al., 1978), including general-purpose soil surveys for agriculture (7), surveys for irrigation projects (7) and some special surveys (4) including two on suitability for particular crops (rice and cotton). On this basis we suggest that the appraisal of legacy surveys which we have undertaken in two provinces of Zambia could be usefully extended, both to the rest of that country and more widely across Africa, if not globally.

3.4. Stakeholder views on legacy and contemporary soil information in Zambia

This section presents the views of stakeholders on the use and value of soil information in Zambia. The participants were from government research and extension, private-sector, non-governmental organizations, and academic institutions as shown in Table 6. Of the fourteen participants who returned questionnaires, along with completed consent forms, ten were male, one was female and three recorded no gender. All of the respondents indicated that they use soil maps, either paper maps or in a GIS form, in their work. 57%, 75%, 64% and 29% of the respondents indicated that they use soil information from their own soil sampling and analysis, soil sampling and analysis by third parties, soil survey reports, and farmers' opinions and experiences, respectively, in making decisions in their work at farm level (Fig. 5a). However, asked about the primary source of soil information used for decision making at farm level, 35.7% indicated soil analysis conducted by their own institution, 29% soil sampling and analysis by third parties, 21.4% soil survey reports and only 7.1% indicated farmers' opinions and experience. When making decisions at regional level, 64%, 50%, 50%, 35% and 21.4% of the respondents indicated they use information from soil sampling and analysis by third parties, own soil sampling and analysis, soil surveys, farmers' opinions and experiences, and opinions from local communities/institutions, respectively (Fig. 5b). 14% of the respondents do not use soil information for decision making at regional level.

Examples of legacy soil information, contemporary soil information—including maps of soil organic carbon and soil pH produced by ordinary kriging (Chabala et al., 2014; 2017) —and descriptions of historical farming systems from Trapnell's traverse records (Smith and Trapnell, 2002) were presented to the stakeholders during the workshop before they were asked to fill in the questionnaires. The views of the stakeholders on use and value of legacy and contemporary soil information and historical farming systems are shown in Tables 7 and 8. Stakeholders thought that the legacy soil information could provide a useful baseline for examining change in soils, and could still be useful for land use planning, as well as being a possible input to new soil information systems through digital soil mapping, but several challenges were mentioned as highlighted in Table 7. In particular, legacy information on some soil properties (pH) may become outdated, and much legacy soil information is integrated with observations on vegetation which have changed dramatically. Making legacy soil readily available and education about its form and value could therefore, potentially increase the use of legacy soil information in in countries like Zambia where the ability to conduct new soil surveys is limited.

With regards to contemporary soil information, most respondents indicated that it is potentially very useful but identified several challenges. In particular, information on soil properties may be too technical for non-experts, and lack the interpretative detail needed for immediate application (Table 7). These findings agree with those reported by Campbell et al., (2017) among European soil information users. It is interesting that several participants thought that a particular feature of the legacy soil information which could usefully be incorporated into the presentation of contemporary soil information was the classification-based structure and associated land use capability assessments which translated more directly into guidance for farmers.

We are not aware of comparable studies on stakeholder appraisal of legacy soil information in other settings. Studies have been done in Europe to investigate the use of soil information by a range of stakeholder organizations (Campbell et al, 2017). This found, among other conclusions, that legacy soil information was regarded as valuable if supplemented by new data both to provide a contemporary picture of the state of the soil and to address new questions. Similarly, in Scotland, Baggaley et al (2019) examined how policy-makers and agencies used maps for soil-based risks to water quality. They concluded that the key challenge was to convert basic soil data into information related to very focussed problems, and that this required improved communication and understanding of stakeholder needs. These general conclusions are compatible with our findings. However, we have not come across any comparable study engaging directly with stakeholders and focussed on soil information and its use in sub-Saharan Africa. We suggest that such studies would be invaluable across the region to identify variations in requirements and to ensure that needs are met before resources are invested in soil survey activities.

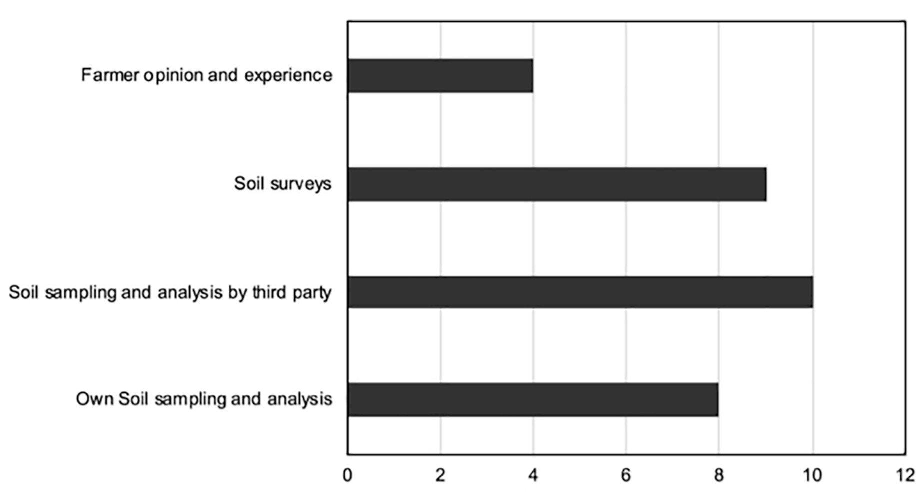

Fig. 5a. Participants' responses on the kind of soil information they use for decision making at farm/field level.

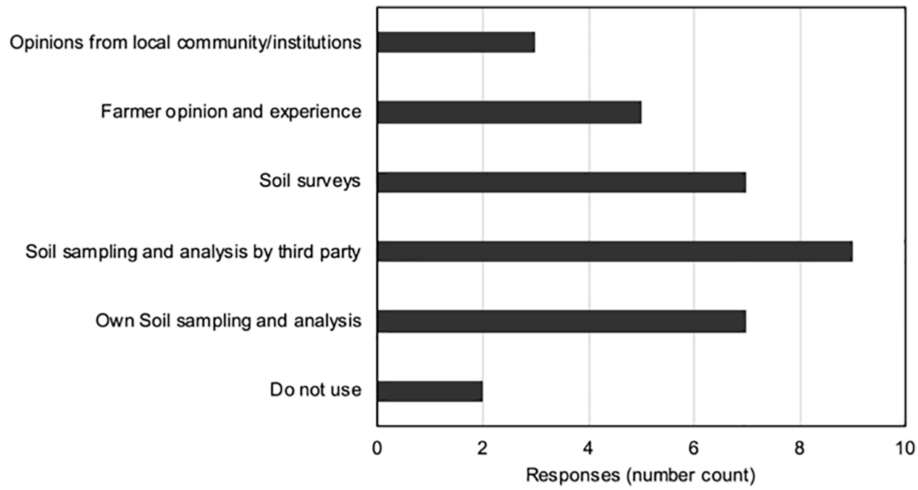

Fig. 5b. Participants' responses on the kind of soil information they use for decision making at regional level.

The historical information on landuse systems from the Trapnell traverse notes were of considerable interest to participants (Table 8), who noted that many features of these systems were adaptations to ongoing challenges for farming, and some could still be seen in use today. Both the farming system information and the information on soil selection principles contained in Trapnell's traverse records could be relevant to wider current interest in how vernacular knowledge of soils can be integrated into adaptation strategies for agriculture under climate change (e.g. Barrera-Bassols et al., 2006). However, while some participants suggested that some of these historical practices might be relevant to resource-poor farmers, there was no suggestion that they might be adopted more broadly.

4. Conclusions

Southern and Eastern Provinces of Zambia have a substantial legacy of soil surveys, and there is no reason to believe that other parts of the country are less-well served. However, much of the legacy is not available, at least in the two major national centres ZARI library and the University of Zambia, or in the ISRIC data base. Memoirs or maps for more than 60% of the conducted surveys could not be traced, while only 22% had both memoirs and map-sheets available and 14% had memoirs but no map-sheets. Given the interest of modern-day stakeholders in this information, and its potential value for contemporary problems, there is an urgent need to recover as much of it as possible, to ensure its preservation in digital formats, and to make it readily available. Comments from the workshop indicate that accessibility also requires ongoing education so that stakeholders understand the legacy information, and so can make best use of it.

Stakeholders recognized the value of contemporary soil information, generated by digital methods, but noted that information on soil properties may require expert interpretation. It was thought that legacy surveys are not just useful sources of information, but provide a model for the provision of information in ways which can be understood, and more directly applied to farmers' problems.

Our assessment of a subset of map-sheets from large-scale legacy surveys in the provinces showed that the publication scale and the texture/complexity of the surveys were not entirely consistent with international norms. This does not necessarily reflect poorly on past surveys as it will reflect, in part, the intricacy of the local soil landscape. Also the map scale consistent with the IMR was often appropriate for the declared use of the survey.

Zambian soil survey is well known because of the historical significance of Trapnell's work (e.g. Tilley, 2011). The landscape which Trapnell investigated is now very different, largely because of the loss of tree cover. However, in a previous study (Mukumbuta et al., 2021), we noted that some soil variations on the Zambian plateau, recognized in more recent surveys, reflected differences in vegetation which Trapnell had observed. This is a reminder that, even in a changing landscape, the imprint of soil forming factors now gone may still be detected, and legacy information will be key, as several participants noted in our workshop, to understanding this. We therefore conclude that the legacy of soil information in Zambia is a valuable resource, but that substantial efforts are needed to restore and preserve it. On the basis of our experience in this study we suggest the following steps. First, an inventory of past surveys should be completed, based on the indices to Soil Survey Section memoirs such as those in our Table 1a, the NORAD (1981) report and interviews with current and retired staff from the Zambia Agriculture Research Institute, University of Zambia and other institutions in the country, and overseas institutions which were engaged in soil survey in the country either during the colonial period or after. Second, urgent steps should be taken to scan survey map sheets and memoirs, and to register the former to cartographic standards. This step in digital preservation of survey reports should ensure that the map sheets are georeferenced and all the meta data is provided so that they can to be retrieved in a usable format.This material should be made available online, open access. Third, painstaking searches for lost material should be undertaken in libraries and archives of ZARI, UNZA, Government Departments and the National Archive of Zambia, and in other libraries and archives internationally. Fourth, close readings of a subsample of this material should be undertaken, following the model of this study, and in collaboration with current and retired experienced soil surveys with a view to understanding and capturing their knowledge and experience of how the information was originally collected and interpreted. While our study of the large-scale surveys collected post-Independence in Zambia is specific to that country, we think it very likely that similar situations pertain elsewhere in Africa, and globally. Some of the activity recommended above, particularly the searches in international archives, could be more efficiently pursued if material for other countries, at least in the region, was sought at the same time, and we suggest that a regional appraisal of the soil information legacy, along the lines of our study, is essential.

Finally, we also note the observation of several of our respondents that contemporary approaches to the provision of soil information typically as maps of single soil properties, at least from the perspective of farmers, are not a panacea, and that aspects of past approaches, exemplified in legacy soil information, model approaches to the provision of information which may better match farmers' needs. In our view this intensifies the urgency of the task we set out in the previous paragraph.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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