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An Investigation into the Spatial and Temporal Distribution of Fallow Land and the Underlying Causes in Southcentral Zimbabwe

Emmanuel Manzungu[1] & Linda Mtali[2]

[1] Department of Soil Science and Agricultural Engineering, Faculty of Agriculture, University of Zimbabwe, Zimbabwe

[2] Department of Science Technology, Harare Polytechnic, Zimbabwe

Correspondence: Emmanuel Manzungu, Department of Soil Science and Agricultural Engineering, Faculty of Agriculture, University of Zimbabwe, Zimbabwe. E-mail: emmanuelmanzungu@gmail.com & manzungu@mweb.co.zw

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Abstract

The purpose of the study was to assess the spatial and temporal distribution of fallow land in Zimbabwean communal lands and the underlying causes against a backdrop of reports of an increasing proportion of agricultural land being left fallow, which has also been reported in other parts of Africa. Chivi district, that is located in the south central part of the country, was used as a case study. Landsat images complemented by field assessments were used to assess changes in fallow land between 1984 and 2010. Standard soil and social science analysis methods were used to assess the likely biophysical and/ or socio-economic causes. The proportion of fallow land was found to increase up to 51.5% during the period, mainly because of socio-economic rather than biophysical factors. Draught power shortage was ranked as the major cause (34%) followed by labor shortage (24%), lack of inputs (22%), and poor soil fertility (16%). Drought was ranked lowest at 4%. Fallow land was mainly used for grazing, which however was of poor quality. The paper concludes that the problem of agricultural land being left fallow land can be solved by seeking alternative land uses other than cropping.

Keywords: fallow land, communal areas, remote sensing, spatial and temporal distribution, socio-economic and biophysical factors, Zimbabwe

1. Introduction

Land distribution has dominated if not defined the agrarian debate in Zimbabwe since the attainment of national independence in 1980. At the centre of the debate was the morality of a white minority population (<1%) utilising 11 million ha of the country's prime agricultural land while 70% of the national population, resident in rural areas known as communal lands, used 16.4 million ha of poor quality land (Moyo, 2006). About 75% of communal lands receive less than 600 mm of rainfall per year (Muir-Leresche, 2006). Due to the poor rainfall patterns, rainfed crop production, the dominant farming system, is severely constrained. Only two out of five agricultural seasons turn out to be good. This is compounded by the fact that most soils in communal lands are granite derived sandy soils that are of poor physical structure, low chemical fertility and low organic matter content (Nyamadzawo, Nyamugafata, Chokowo, & Giller, 2003). Crop production is reported to suffer from major nutrient deficiencies such as nitrogen (Zingore, Murwira, Delve, & Giller, 2007), mostly due to poor access to inputs and markets, and poor information dissemination strategies (Mapfumo, Mtambanengwe, Giller, & Mpepereki, 2005). Livestock production is also constrained by lack of adequate grazing due to poor rainfall, and poor management practices (Sibanda & Khombe 2006). The poor agricultural conditions have resulted in increasing quantities of land left to fallow (Mapfumo et al, 2005; Chuma, Mombeshora, Murwira, & Chikuvire, 2000; Cavendish, 1999), which has also been reported in Eastern and Southern Africa (International Coorperation with Developing Countries [Inco-dev], 2004). No wonder food insecurity is common as has been reported for the rest of sub-Saharan Africa (United Nations Economic and Social Council [UNESC], 2009; International Federation of Red Cross and Red Crescent Societies [IFRRS], 2009).

Agriculture is the main source of livelihoods in most Zimbabwean communal lands. Communal lands account for 42% of the national land area (Muir-Leresche, 2006). It is therefore important to closely examine the paradox of agricultural land being left fallow in terms of its spatial and temporal distribution as well as the underlying causes (Kusangaya, Manzungu, & Mazvimavi, 2004; Rajan & Shibasaki, 1997). In this respect the quantification of land use and land cover is crucial (Chinembiri, Lynam, Mombeshora, Rupiya, & Cunliffe, 2004).

In Zimbabwe remote sensing studies to assess land use and land cover changes have traditionally been done using aerial photographs (Kusangaya et al., 2004; Mapedza, Wright, & Fawcett, 2003; Whitlow & Zinyama, 1988). However, these are being phased out in favor of satellite images that can be accessed free of charge and have a higher temporal resolution (Sibanda & Murwira, 2012; Murwira & Skidmore, 2006). The wide availability and increasing application of Geographical Information Systems (GIS) technology has enhanced the application of satellite images (Kusangaya et al., 2004; Pandey & Nathawat, 2002; Economic and Social Commission for Africa and the Pacific [ESCAP], 1997). A number of studies have used satellite images to assess land use changes in Zimbabwe in rural and urban areas alike (Kamusoko & Aniya, 2007; Matsa & Murinaniza 2011; Murwira, Skidmore, Huizing, & Prins, 2009; Kusena, 2009; Prince, Becker-Reshef, & Rishmawi, 2008; Mambo & Archer, 2008). However, there have been no studies that focus on the documentation of agricultural land being left to fallow for indefinite periods of time.

Successful application of satellite images (and remote sensing techniques in general) to assess land use and land cover change depends on the existence of distinct and verifiable textural differences of land cover classes. This is because the techniques are based on visual interpretation of images (Matsa & Muringaniza, 2011; Murwira et al., 2009; Kusena, 2009; Kamusoko & Aniya, 2007). However, in some cases, visual image interpretation may not be adequate. In such cases vegetation indices are used so as to more accurately differentiate homogenous land cover classes from each other. For example Sibanda and Murwira (2012) used vegetation indices to differentiate between maize and cotton fields, both of which fall under the land cover class of agriculture. Such a challenge is encountered when attempting to differentiate between cultivated lands from fallow land. This study sought to quantitatively assess the changes in fallow land cover in Zimbabwean communal lands between 1984 and 2010 as well as identify the underlying factors. Chivi district, which is located in south central Zimbabwe, was used as a case study.

2. Materials and Methods

2.1 Study Area

The general study area was Chivi district that lies some 400 km southeast of Harare, Zimbabwe's capital (Figure 1) while the specific study area was ward 28 under Chief Gororo. In terms of the country's administrative structure, a ward is the smallest administrative and planning unit above which is found the district and province. In general 15 to 25 traditional villages make up a ward. Ward 28 is composed of 20 such villages. Field work was conducted in four villages, namely, Madziva, Mutsure, Tibha and Gororo (Table 1).

Table 1. Characteristics of the four study villages in ward 28, Chivi district

Name of village	No. of households
Gororo	23
Madziva	41
Mutsure	35
Tibha	31
Total	130

Chivi is one of the driest districts in Zimbabwe. It falls in agro-ecological region (V), which receives an average annual rainfall of 450 mm. The district experiences recurring droughts. This was confirmed by an analysis of drought between 1941 and 1992 that showed that one in 5 years could be classified as having severe or very severe drought (Scoones et al., 1996). Drought has a severe impact on the livelihoods of the people. For example, droughts that occurred in 1982 and 1992 resulted in severe crop failure and livestock mortality estimated at between 50 and 70% (Defoer, 2002; Bird, Scott, & Butaumocho, 2002; Chuma et al., 2000; Cavendish, 1999).

Food security is generally poor in the area because subsistence agriculture, which is the main source of livelihood in the area, is negatively affected by the semi-arid conditions that prevail in the area.

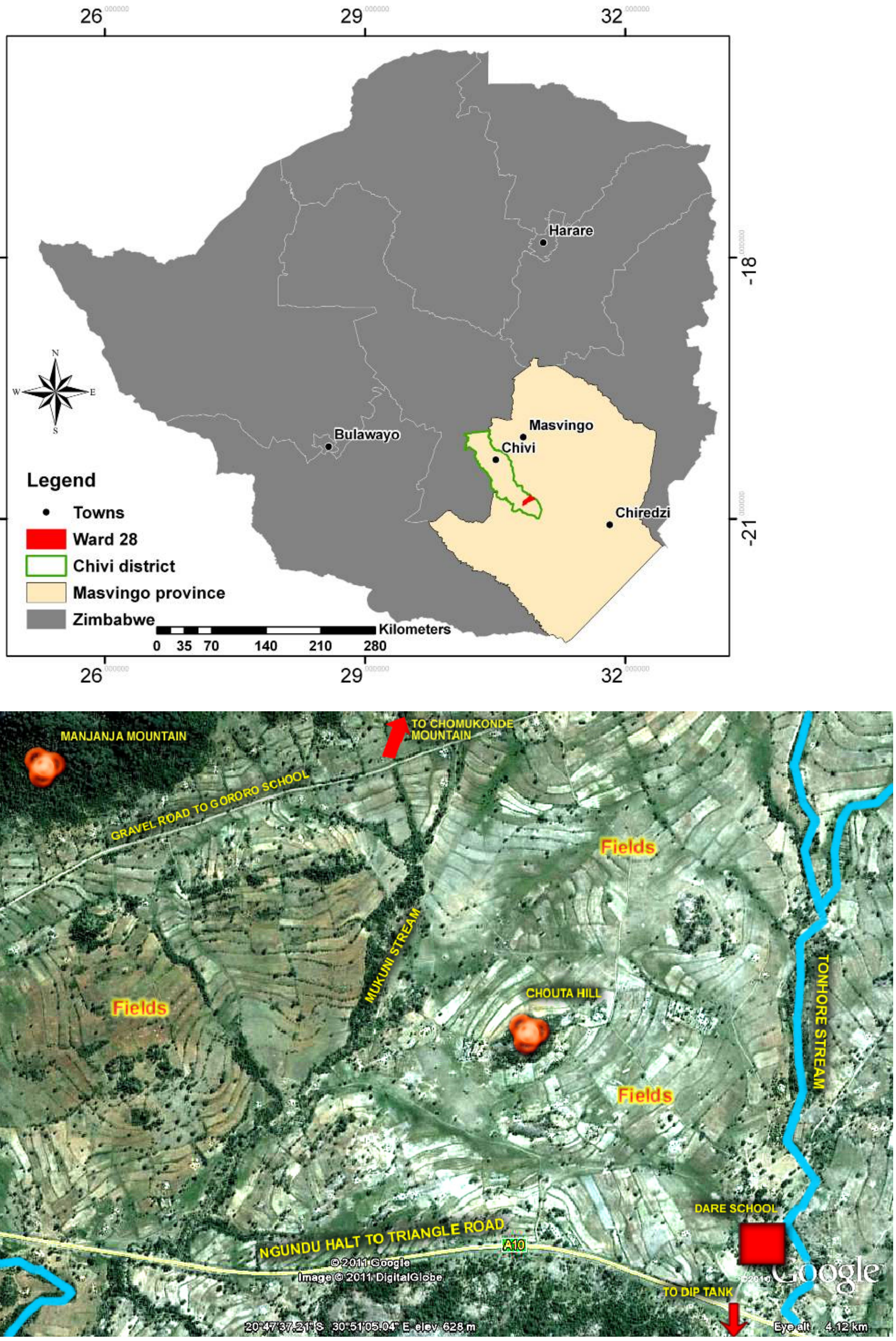

Figure 1. Location of ward 28, Chivi district, and general features of part of the ward that constituted the study area (from Google earth and participatory mapping)

Low crop yields are realized because of poor rainfall and poor soil fertility (Mapanda & Muvengahama, 2011; Scoones et al., 1996; Nyamapfene, 1991). The major crops that are grown include maize and sorghum, and rice which is grown on wetlands (Chuma et al., 2000). Subsistence-oriented livestock production that includes cattle (mainly for draught power), goats and poultry is also under threat.

2.2 Determination of Fallow Land

Preliminary assessment of satellite images in the laboratory indicated that there were five distinct land cover types in the study area (Table 2). Fallow fields and natural grassland were classified under one category. At this stage they could not be differentiated because of similar reflectance. Village heads of the four villages assisted with field verification of the different land classes particularly of fallow land. Location points from the different land cover classes in the field were identified. These were used during image classification as ground control points, which were meant to give a sample set of reference points for each cover class during image classification. Five main steps were followed in determining the spatial changes in fallow land (Table 3).

Table 2. Description of the different land cover classes that were used in the study

Land cover class	Description
Cultivated land	Fields cultivated continuously since 1984
Fallow land/grassland	Fields that were once cultivated and then abandoned including grassland that was never cultivated
Woodland	Area which had woody cover and had never been cultivated
Bare	Areas without any vegetation cover including rock outcrops
Water	Deep and shallow water in dams, streams and rivers

Table 3. Overview of the methodological approach used during land cover assessment

Step	Main activity
1	Compilation and preparation of landsat images, aerial photographs and identification of location data required for image classification
2	Preliminary assessment of satellite images, conversion of Landsat images to NDVI. Classification of NDVI Landsat images into different landcover classes
3	Accuracy assessment of classified images
4	Delineation of arable land
5	Quantification of changes in area under fallow

Landsat images acquired on 12 April 1984, 4 May 1986, 26 March 1995, 17 April 2009 and 6 May 2010, covering a six-week period that coincided with the cropping season in the study district, were used to determine land cover changes. The images were downloaded from www.glovis.usgs.gov. A sample of five location points for each of the different land cover classes (ground control points) were identified from the field using a Global Positioning System (GPS), e-Trex HC series, and from the Google Earth image of 2011 (http://earth.google.com). This was undertaken in March 2011.

These ground control points were later used in the classification of the satellite images. Aerial photographs acquired in August 1985 and July 1996 from the Department of Surveyor General in Harare (Zimbabwe's capital) were used to establish a sample of ground control points as an essential step in separating arable from non arable land. All landsat images and aerial photographs were geo-referenced to UTM zone 36 coordinate system. Landsat images were converted to Normalized Vegetation Index (NDVI) data composites in ENVI (www.ittvis.com). NDVI was calculated using the following equation:

$$NDVI = \frac{\rho NIR - \rho R}{\rho NIR + \rho R}$$

where ρNIR is reflectance in the Near Infra-red and ρR is reflectance in the Red band (Lilisand & Kheifer, 2000).

NDVI images were used to distinguish between different land cover classes from each other because the values for each land cover class remained consistent throughout the process of image classification. This showed that for this exercise NDVI values are more appropriate compared to visual image classification. A sample set for NDVI range of values for each of the different land cover types were derived by overlaying landcover polygon maps with ground control points from GPS surveyed fields and from 2011 Google earth satellite image onto the

2010 NDVI derived satellite image in ILWIS GIS (International Institute for Geo-Information Science and Earth Observation [ITC], 2005). To ascertain the statistical difference between the different land classes, the respective NDVI reflectance values for each cover class were subjected to a 5 % least significant difference test.

The upper and lower boundary values for each NDVI land cover class were calculated using 95% Confidence Interval (95% CI) of the NDVI mean values. These were then used to calibrate a land cover classification domain in ILWIS GIS. Using the created land cover domain all the NDVI maps (for the years 2010, 2009, 1995, 1986 and 1984) were classified into their different landcover types (Figure 2). Aerial photographs acquired in 1985 and 1996, together with Google Earth satellite image of 2011, were used to establish sample sets of ground control points for accuracy assessment of the classified satellite images. The classified images of 1984, 1986, 1995, 2009 and 2010 had an overall accuracy of 0.86, 0.85, 0.83, 0.87 and 0.88 respectively.

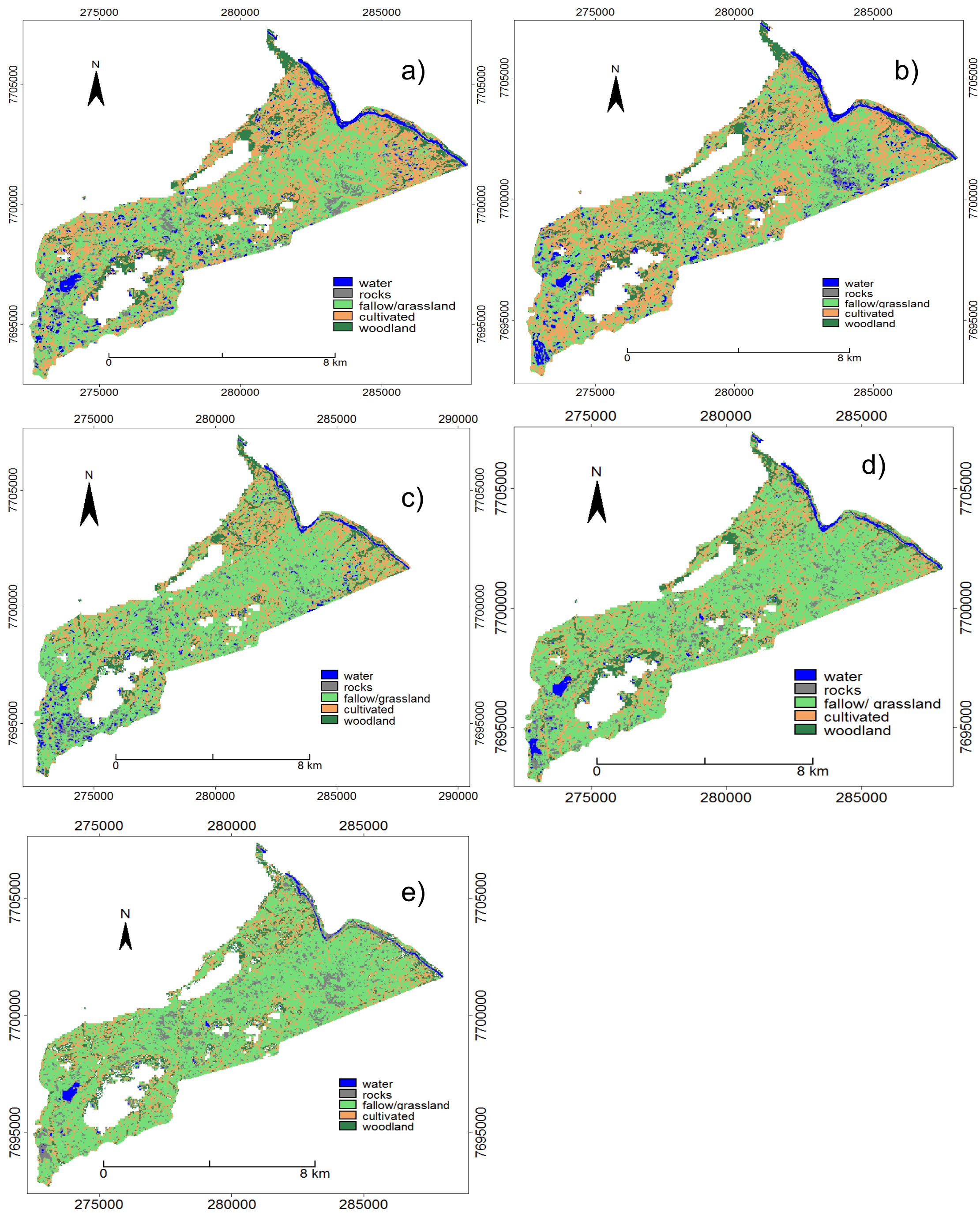

Figure 2. Land cover changes in Chivi ward 28 for the years; a) 1984, b) 1986, c) 1995, d) 2009 and e) 2011

To assess the extent of arable land aerial photographs were used to generate control points that were used to separate potentially arable land from the non-arable. Stereo-pairs of aerial photographs were used to differentiate mountains from valleys and level ground. The Digital Elevation Model (DEM) (http://www.gdem.aster.ersdac.or.jp/outline.jsp) was used to separate arable land from non arable land. The separation in the first instance was based on elevation by overlaying non-arable mountainous points from the aerial photographs on the Digital Elevation Model. Areas with an altitude above 690 m were considered to be non-arable (Figure 2). Area that was covered by water, bare/rocks and woodland was also considered to be non-arable. Arable land was found to be composed of two cover classes, namely cultivated and fallow/grassland. In order to differentiate fallow from natural grassland, fallow land was determined as the difference between cultivated land in 1984 and the subsequent years up to 2010.

2.3 Determination of Underlying Causes

Both socio-economic and biophysical factors were assessed. Socio-economic data was collected through the use of key informant interviews and administering a questionnaire survey. Information that was sought included distribution of cultivated and fallow fields, household characteristics of the four villages, as well as the underlying causes for indefinite fallowing. A participatory workshop was held to ascertain and verify data collected from the interviews and survey. Survey data was analyzed using Statistical Package for Social Sciences (SPSS) 13^{th} edition.

Soil samples were collected from fallow fields of different ages, namely; 0-2, 2-5, 5-10, 10-15 and 15-30 years. Cultivated fields and woodland acted as the control. Samples were collected during the cropping season from a plough depth of 20 cm using a soil auger. The samples were air-dried, ground and passed through a 2 mm sieve prior to determination of mineral N. Available P, K, Ca, Mg and pH were also analyzed (Table 4). For the various soil parameters, statistical differences of means were calculated using general analysis of variance in Genstat 13^{th} edition.

Table 4. Methods used to analyze soil parameters

Nutrient element/ data	Method of analysis
Mineral N	The incubation technique (Saunder, Ellis, & Hall, 1957) was used to estimate mineral N that was extracted using KCl solution and determined spectroscopically
Available P	Extracted by the Resin method (Anderson & Ingrams, 1993) and determined spectroscopically
K, Ca, Mg	Exchangeable bases determined after extraction with ammonium acetate (Summer & Miller, 1996). Concentrations of exchangeable K were determined by flame emission photometry, while Ca and Mg were determined by atomic absorption spectrophotometer.
pH	Measured with a pH meter in a 1:5 soil: $CaCl_2$ suspension (Anderson & Ingrams, 1993)
Soil texture	Relative proportion of sand, silt and clay in the soil from each treatment determined using the Bouyoucos hydrometer method (Gee & Bauder, 1986), while a soil texture triangle (Food and Agriculture Organisation [FAO], 1990) was used to determine the texture category.

3. Results and Discussion

3.1 Extent of Fallow Land

The gross area of ward 28 was found to be 8 230 ha of which 6 700 ha or 81% was initially classified as arable. In this preliminary classification, non-arable land was made up of mountains and hills above 690 m above sea level. Land covered by water, woodland, bare/rocks was found to cover 16 % of the total ward area. Land that was delineated as arable land, which constituted of cultivated/ grassland, was found to constitute 5 380 ha in size or 65% of the whole ward. Figure 3 shows the proportions of the various land cover classes over the study period.

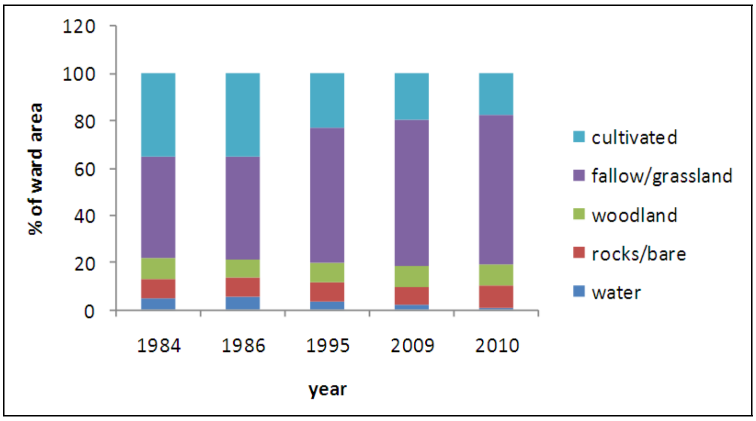

Figure 3. Proportion of land under different classes in ward 28, Chivi district

Land cover over the study period was observed to be changing, with some cover classes changing with greater magnitude than others, whilst some remained relatively constant. For example, between 1995 and 2010, there was no observed decrease in woodland indicating that little or no new land was cleared for cultivation. This suggests that most of the land was cleared before (in the 1960s) during the introduction of the plough (Scoones et al., 1996). Water cover class, however, declined over the years. This could be attributed to a combination of changes in rainfall patterns and drying up of streams and wetlands (Mapanda & Mavengahama, 2011). Between 1995 and 2010 cultivated land decreased by 18 %. By 2010 more than 50% of the fields were found to be fallow (Figure 4). The reasons are discussed in the next section.

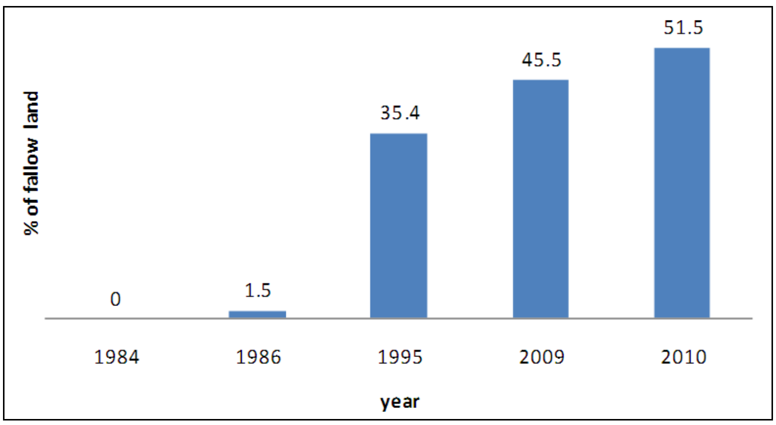

Figure 4. Change in the proportion of fallow land in ward 28, Chivi district between 1984 and 2010

All fallow fields were found to be mainly covered with grass and showed little or no bush encroachment over the 30 year period. This was probably because of overgrazing in the area that prevented regeneration of vegetation (Chuma et al., 2000). The harsh biophysical conditions, such as low precipitation and poor soil fertility, could also have been responsible. Apparently fallowing is increasing in smallholder agriculture in Zimbabwe. Increasing fallow was also reported in other studies (Scoones, 2001; Chuma et al., 2000; Cavendish, 1999; Scoones et al., 1996). The area under maize crops was also observed to be decreasing significantly throughout the country even in seasons with adequate rainfall (United States Department of Agriculture [USDA], 2009).

3.2 Causes of Fallowing

Respondents cited lack of draught power, labor shortage, poor soil fertility, lack of inputs and drought as the leading causes for increasing fallow land. However, as can be seen from Figure 5, these were not weighted equally by the respondents. Labor shortages were given as the first main reason followed by draught power shortages, which indicates the importance of these two as sources of power in farming activities.

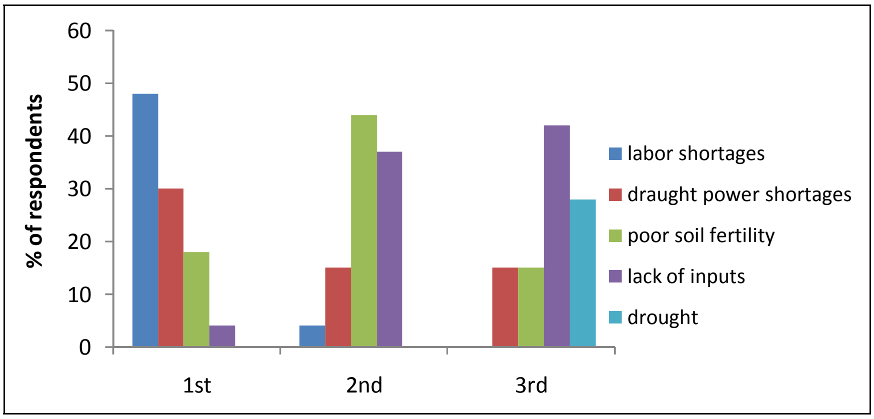

Figure 5. Respondents' reasons for leaving fields fallow in Ward 28, Chivi district

Figure 6 shows the relative frequencies of the various reasons that were advanced as explaining the incidence of fallow land. An interesting observation is that the first three important reasons were socio-economic rather than biophysical. Only 4% of the respondents cited drought as the reason for cultivated land being left fallow despite the district being one of the driest in Zimbabwe. This suggests that communal farmers in this district regarded drought as an ever present threat that did not affect changes in cultivation patterns. Socio-economic factors that were identified were symptomatic of smallholder agriculture in general. Smallholder agriculture has been known to suffer from shortage of seed, fertilizers and farm equipment due to widespread poverty reflected by, among other things, food insecurity, unemployment and income levels of less than US$1 per day (Government of Zimbabwe, 2004). Inadequate infrastructure development (Mehretu & Mutambirwa, 2006; Bird et al., 2002) and weak institutional capacity especially in relation to extension services and farmer organization, and poor markets were also cited (Mapfumo et al., 2005; Vincent, Leewis, Manzungu, & Moll, 2004; Manzungu, 2004; Hagmann, Chuma, Connolly, & Murwira, 2000).

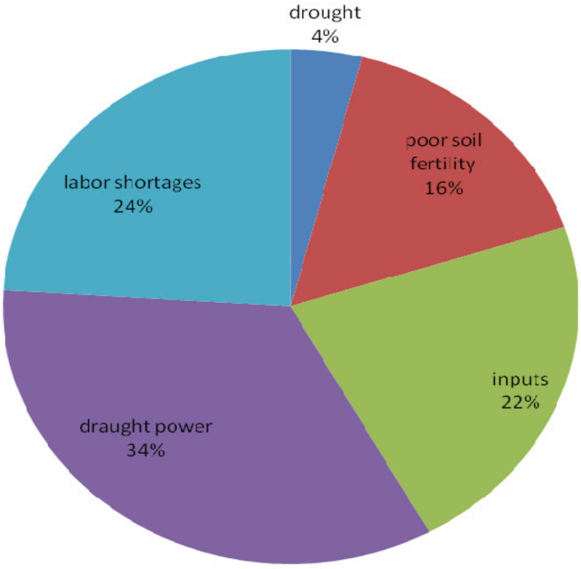

Figure 6. Farmers' reasons for leaving land fallow Ward 28, Chivi district

Draught power shortage was cited as the main cause of fallowing, because of poor livestock numbers in the community, and also because it took long for livestock to recover from drought shocks (Bird et al., 2002). An average of two cattle per household was recorded in the area. Cattle ownership was unevenly distributed among households with more than 35% of the households owning no cattle at all (Figure 7).

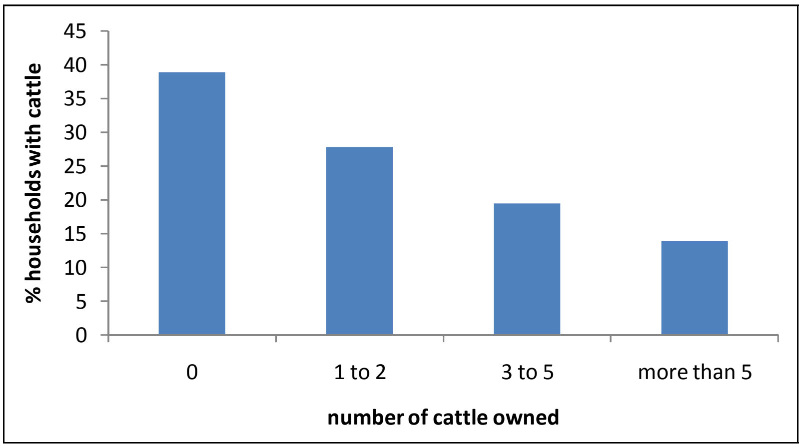

Figure 7. Cattle ownership in ward 28, Chivi district

Labor shortage was ranked second major reason because family members were too young to provide farm labor, as well as migration and death or a combination of factors (Figure 8). Migration was one of the single biggest reasons for labor shortages. The high unemployment rates, coupled by high inflation rates of the local currency, had resulted in high levels of migration mostly to South Africa and Botswana.

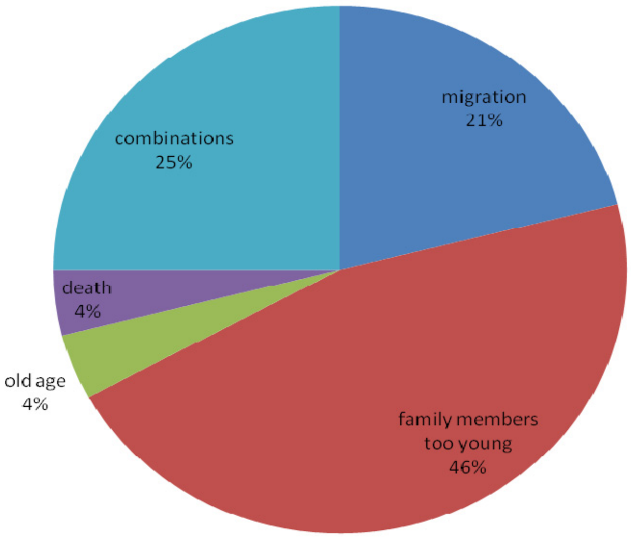

Figure 8. Reasons for labor shortages in Ward 28, Chivi district

Shortages of inputs were cited as responsible for fallowing by a fifth of the population (see Figure 6) because of the low income status of the respondents. Farmers claimed to be too poor to afford purchasing necessary inputs required to cultivate their entire fields. The low average incomes support this assertion (Figure 9).

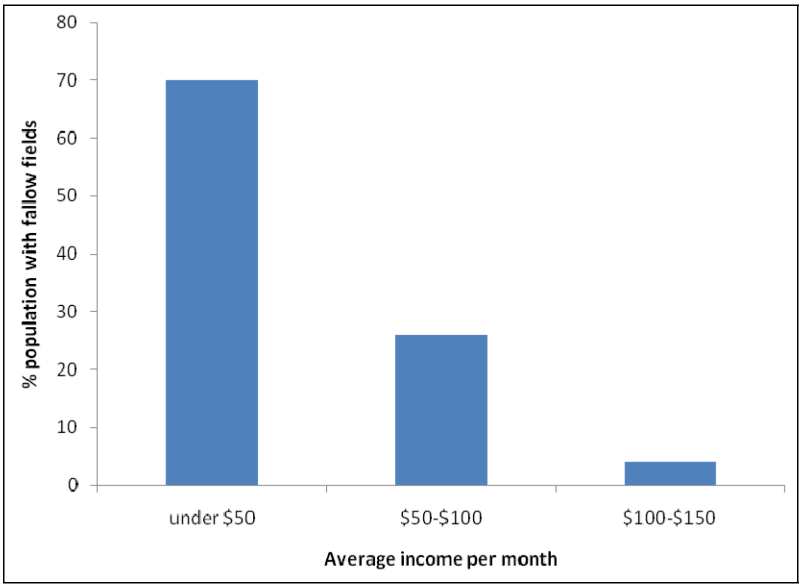

Figure 9. Distribution of average income per month in ward 28, Chivi district

The poor soil status means that farmers needed to raise a lot of money to improve soil fertility. Poor soil fertility was confirmed by laboratory soil analysis that encompassed analysis of soil texture, and soil nutrients (N, P, K, Mg and Ca) and soil pH (Table 5). Farmers were not in a position to purchase the necessary fertilizers. This problem also occurs in other parts of sub-Saharan Africa because of a poor commercial fertiliser industry, supply, knowledge, biophysical factors and poor markets (Poulton, Kydd, & Dorward, 2006).

Table 5. Nutrient content and pH values for soils in fallow fields of different ages, cultivated fields and woodlands in ward 28, Chivi district

Nutrient	Range	Mean
Mineral nitrogen	12.6-18.7ppm	14.7ppm
Available phosphorus	3.8ppm- 4.4ppm	3.9ppm
Potassium	0.07- 0.13ppm	0.09ppm
Calcium	0.7- 1.4 cmol/kg of soil	0.9 cmol/kg of soil
Magnesium	0.4- 0.5 cmol/kg of soil	0.44cmol/kg of soil
pH	4.3- 4.6	4.4

The woodland class was found to significantly have higher nutrient content ($p < 0.05$) than all other treatments. The only exception was mineral N that was higher in cultivated fields possibly because of residual N from organic and inorganic fertilizers.

The relatively high pH values and high Ca and Mg content in woodland could be explained by high organic matter content from leaf litter. The overall low values of available P were because of the low inherent P coupled with high soil acidity (Mapanda & Muvengahama, 2011; Nyamangara, Mugwira, & Mpofu, 2000). Soil acidity reduces P availability by changing it to forms that make it unavailable for crop uptake.

All the samples fell under three textural classes, namely, sandy, loamy sandy and sandy loam (Figure 10). Loamy sand made up 51 % of the samples, while 18 % were sandy and 31 % were sandy loam. Such soils are characterized by poor physical properties such as low water holding capacity, low organic matter content, high organic matter turnover rate, and low buffering capacity (Mapanda & Mavengahama, 2011; Mtambanegwe & Mapfumo, 2005).

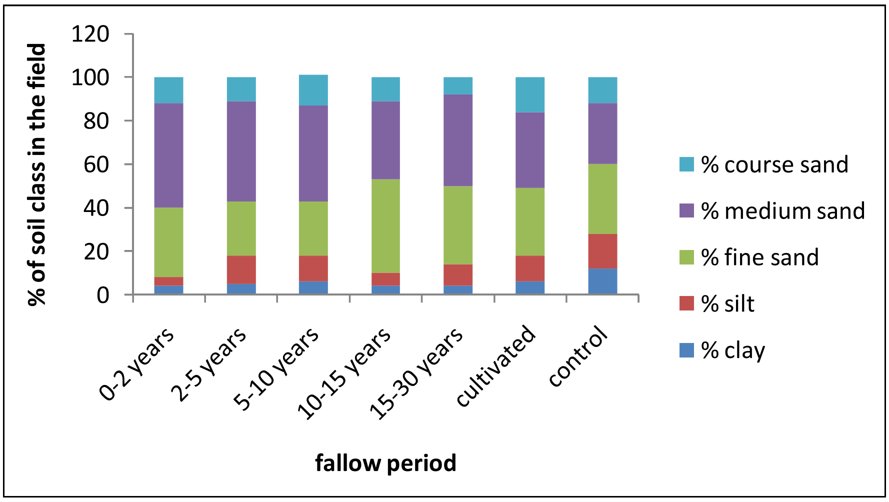

Figure 10. Soil texture classes of the sampled fields in ward 28, Chivi district

Due to a combination of these factors land was increasingly being left fallow, and was used for grazing as cited by 85% of the respondents. However, the grazing quality of the vegetation was found to be poor (Chimombe, 2011), which has been documented for the generality of communal areas (Sibanda & Khombe, 2006).

4. Conclusions

This study was aimed at quantifying the spatial and temporal distribution of fallow in Zimbabwe communal lands as well as identifying the underlying reasons. Chivi district was used as a case study to investigate the distribution of fallow land between 1984 and 2010. Between 1984 and 2010 fallow land was shown to increase in Chivi communal lands by almost half the size of the land that was cultivated in 1984. The factors contributing to increase in fallowing were categorized as shortages of draught power, labor shortages, lack of inputs, low soil fertility and drought. In all cases the reasons were found to be more socio-economic than biophysical. These factors were, however, interlinked. For example inputs for soil fertility, such as fertilizers and lime, could not be purchased because of low incomes. These problems were found not to be unique to Zimbabwe. Other parts of African continent suffered the same problems.

Satellite images were found capable of replacing expensive surveys to document land use change. However, there is a challenge in separating some homogenous features such as fallow (dominated with grass) from natural grass cover. This is because homogenous surfaces tend to have overlapping reflectance values making it difficult to distinguish between them. In such instances the use of vegetation indices can make a difference.

There is a clear need to address the phenomenon of increasing area of fallow land in Zimbabwe against a backdrop of food insecurity. One way is not to think of food security in terms of food production. In this respect it is important to search for better and sustainable land utilization. This study has shown that fallow land is increasingly being used for grazing. There was, however, a need to improve the quality of the grazing.

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