Received: 9 January 2023 | Accepted: 24 April 2023 | Published online: 18 September 2023

DOI: 10.1002/agj2.21365

Agronomy Journal

NOTES AND INSIGHTS

Agronomy, Soils, and Environmental Quality

Natural recovery of old crop fields in a South African grassland biome

Willem G. Coetzer[1,2] | **Kayleigh Coetzer**[3]

[1]Department of Zoology and Entomology, University of Fort Hare, Eastern Cape, South Africa

[2]Department of Genetics, University of the Free State, Bloemfontein, South Africa

[3]School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa

Correspondence
Willem G. Coetzer, Department of Zoology and Entomology, University of Fort Hare, Eastern Cape, South Africa.
Email: coetzerwg@outlook.com

Assigned to Associate Editor Nothabo Dube.

Funding information
Department of Genetics, University of the Free State, Grant/Award Number: 10.13039/501100004765

Abstract

Changing land-use practices have led to an increased rate of cropland abandonment in South Africa. Globally, climate change has increased the need for additional studies on the impact of land abandonment on soil health in arid and semi-arid environments. We, therefore, aimed to measure the changes in soil health with time following abandonment. The study site is located in the Winterberg Mountains of the Eastern Cape Province, South Africa. Standard soil characteristics were assessed for three recovering old crop fields. Samples from the surrounding natural habitat were also included for comparison. Significant positive changes in soil water-holding capacity and carbon and nitrogen characteristics were observed with increased age since abandonment, pointing to soil quality recovery. It will, however, still take a significant amount of time for total recovery to be achieved. Continuous monitoring of old crop fields in agricultural and formally protected areas is needed to fully understand the long-term effects of cropping on soil quality in this region.

1 | INTRODUCTION

Over the last few decades, cropland abandonment for natural recovery has increased worldwide due to changing weather patterns and shifts in the rainy seasons (Benhin, 2008; Blair et al., 2018; Bradley et al., 2012; Rey Benayas et al., 2007). Climate change has also greatly affected crop farming in South Africa, where 13.7% of land is used for intensive agriculture (Jacobs et al., 2018). Many croplands are, however, being abandoned due to changing land-use practices and increased use for livestock grazing (Suich & Boardman, 2017) or through the establishment of nature conservation areas (Ruwanza, 2017; van Rooyen et al., 2010). The rehabilitation process of these old crop fields is generally approached through either active (i.e., seed planting of natural plants; Wang et al., 2020) or passive rehabilitation (i.e., natural recovery; Valkó et al., 2017).

The positive effects of active and passive vegetation regeneration on soil quality parameters are well documented. A meta-analysis of 101 published field studies from China reported by Huang et al. (2020) showed significant increases in soil total nitrogen (TN) and total phosphorus (TP) following vegetation recovery. Soil organic carbon (SOC) and mineralized soil total inorganic N (MTIN) were shown to increase with the years of fallow in the Bolivian Andean Highland Region (Aguilera et al., 2013). In South Africa, Ruwanza (2017) showed that micro-topography within Renosterveld old fields plays a crucial role in native Renosterveld species recovery, with higher levels of soil fertility observed in furrows compared to ridges. These results further supported similar observations by Memiaghe (2008) at abandoned fields in the Western Cape provinces. Many other studies have also shown how soil quality can improve following cropland abandonment across the world, from the Canadian prairies (An et al., 2019), the Canary Islands (Arévalo et al., 2017), Australia (Geddes et al., 2011), and semi-arid regions in Iran (Heydari et al., 2020).

The Eastern Cape Province of South Africa is a highly mountainous region. Extensive mountain ranges, forming part of the Great Escarpment (Clark et al., 2011) and the eastern limits of the Cape Fold Mountains (Miller et al., 2016), dominate the landscape. The Eastern Cape mountains are biologically highly diverse areas, with high levels of endemism observed (Clark et al., 2009, 2014). Many studies conducted in South Africa focused on the influence of cropping, including the use of different cropping techniques, on soil quality (Gura & Mnkeni, 2019; Mupambwa & Wakindiki, 2012; Muzangwa et al., 2021; Njaimwe et al., 2018). Some studies also assessed the change in soil properties due to factors such as soil erosion (Ighodaro et al., 2013; Oluwole & Sikhalazo, 2008), woody vegetation encroachment (Masibonge et al., 2020), and change in vegetation type (Mills & Fey, 2004), which can be linked to improper livestock management practices. Shackleton et al. (2013) performed a soil health assessment of a series of abandoned crop fields in the Wild Coast region (a coastal, high-rainfall area) of the Eastern Cape Province, South Africa. These authors found a significant increase in carbon levels as the age of the old crop fields increased. A significant change in soil compaction was also observed, with older fields showing lower levels of compaction (Shackleton et al., 2013). This is one of the few studies on the change in soil quality following the natural recovery of crop fields available from the Eastern Cape Province of South Africa.

The aim of this study was, therefore, to assess the variation in soil properties between differently aged, recovering old crop fields and the surrounding natural grassland in the Winterberg Mountains of the Eastern Cape Province, South Africa, situated in the Arid, Steppe, and Cold (Bsk) Köppen-Geiger climate region (Beck et al., 2018). In contrast to the Shackleton et al. (2013) study, the study site is located in a mountainous region with a lower annual rainfall record.

Core Ideas

- Cropland abandonment is a global occurrence, with old croplands allowed to recover to a natural state.
- Limited studies have been conducted on cropland abandonment.
- Water-holding capacity, N percentage, and C percentage increase with abandonment age.

2 | MATERIALS AND METHODS

2.1 | Sample site

The sample sites are located on a private farm (Leliekloof farm) situated within the Great Winterberg mountain range, 55 km south-east of Cradock, Chris Hani District, Eastern Cape Province (32˚19′37.4″S, 26˚01′08.0″E). This region is situated in the Arid, Steppe, and Cold (Bsk) Köppen-Geiger climate region (Beck et al., 2018). The naturally recovering old crop fields selected for this study are located on a plateau region on the farm at an average elevation of 1,658 m above sea level (m.a.s.l.). These crop fields were first established in 1963 (J.M. Coetzer, personal communication, April 2021). This area falls in the Grassland Biome and is represented by the Karoo Escarpment grassland vegetation type (mixture of shrubs and grasses; Mucina & Rutherford, 2006). The geology of the region is represented by the Adelaide subgroup of the Beaufort Group of sedimentary layers as well as Karoo Dolerite intrusions (Council for Geoscience, 2021). The average annual rainfall for the region is 547 mm per year (1970–2000; Fick & Hijmans, 2017), with the average rainfall between 2016 and 2021 for the farm recorded as 365 mm (J.M. Coetzer, personal communication, April 2021).

On the study site, several naturally recovering old crop fields reside that have not been cropped or tilled since 1989, 1997, and 2009, respectively (Figure 1). These old fields have started to slowly recover in terms of natural vegetation. The old fields are surrounded by natural grassland, which has never been cropped, and the whole camp is used for grazing by sheep, goats, and cattle on a rotational grazing system. Upon visual inspection, it can be seen that the old crop field sections show a difference in vegetation composition compared to the neighboring natural areas. The old crop fields are mostly dominated by *Eragrostis* grasses and *Chrysocoma ciliata* dwarf shrubs, whereas the surrounding natural veld is dominated by *Merxmuellera (Tenaxia) disticha* and *Themeda triandra* grasses.

2.2 | Soil sampling

Four sampling localities were selected for this assessment. Soil samples were collected from three sites in each of three recovering old crop field sections of three age groups (1989, 1997, and 2009) and a control site of natural grassland (Nat) bordering the fields, which has never been used for croplands (Figure 1). Sampling was performed in December 2020. Each soil sample consisted of three subsamples to account for any

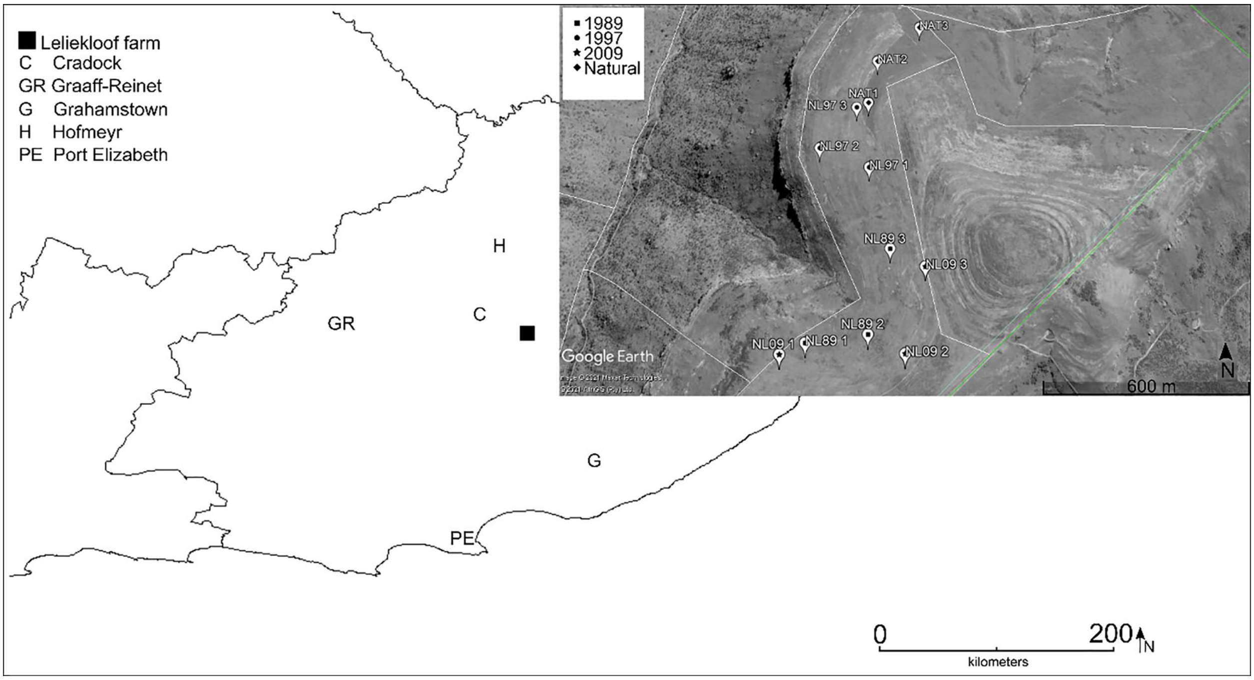

FIGURE 1 The location of the study location within the Eastern Cape Province is displayed in the main map (black square). The individual sample sites are shown on the map extracted from Google Earth Pro (Google Earth Pro, 2021).

variability within each locality and was collected in a 20 m transect at 10 m intervals. Each subsample was collected with an auger to a depth of 10 cm. This gave us a total of 12 soil samples across all four localities.

An additional 12 samples were collected at the same sites (Figure 1) with a 4.5 cm diameter PVC pipe corer to a depth of 4 cm. The samples were immediately placed in separate sealable bags to minimize water loss. These samples were used to determine the bulk density of the soil. Each sample was taken by carefully pushing the corer into the soil and limiting soil disruption as much as possible.

2.3 | Soil analysis

In-depth details on the analyses with appropriate citations are available in Supporting Information 1. In summary, the 12 composite samples taken at 10 cm depth were dried at 100˚C for 72 h prior to analyses. All samples were sieved (2 mm) to remove stones and large plant material prior to drying. These sieved samples were used to assess the following soil characteristics: pH, total dissolved solids (TDS), and electrical conductivity (EC) measured using an ExStik II pH/Conductivity meter (Extech Instruments); soil texture following the Hydrometer Method (Gee & Bauder, 1986); soil water-holding capacity (WHC) following a modified version of the methods by Jenkinson and Powlson (1976) and Bhadha et al. (2017); as well as carbon and nitrogen properties via dry combustion (Nelson & Sommers, 1983) using a TruSpec Leco CN analyzer (LECO Corp.). Soil bulk density was further estimated from the 4 cm samples using the known corer diameter and depth (Supporting Information 1).

2.4 | Statistical analyses

A Mantel test (Mantel, 1967) was performed to test for spatial autocorrelation in the data using the ade4 package (Dray & Dufour, 2007) in R (R Core Team, 2021). The GPS coordinates of each sample site were measured with a Garmin eTrex 10 GPS device and used to calculate a distance matrix for comparison to a distance matrix estimated from all soil characteristics. The soil characteristics measured in this study were compared between old crop field age groups (1989, 1997, and 2009) and the natural grassland using a multivariate linear regression assessment in PAST v4.01 (Hammer et al., 2001). The measurements for soil bulk density, pH, TDS, N percentage, C percentage, N stock, C stock, WHC, and soil texture (sand, silt, and clay) were set as dependent variables. The age class was set as the independent variable. The ages since abandonment were calculated for each site, with an age of 60 years selected for the natural habitats as the first crops were planted in 1963 (J.M. Coetzer, personal communication, April 2021). Setting the age of the natural habitats to 40, 100, or 150 did not have any significant changes to the regression analysis results.

Non-metric multidimensional scaling (NMDS) was performed to visualize similarities between treatments using the

R package VEGAN (Dixon, 2003; Oksanen et al., 2007). The NMDS plot was produced using a Gower's dissimilarity matrix (Gower, 1971) produced from all calculated measures. Gower's index was selected as it has been shown to be reliable when using several types of variables (Legendre & Legendre, 2012; Pavoine et al., 2009).

3 | RESULTS AND DISCUSSION

The Mantel test showed no significant correlation between soil characteristics and spatial distance ($p = 0.114$). The summary statistics for all parameters are provided in Table S1. The soil texture results from the current study identify the soil as having a sandy loam texture (Hazelton & Murphy, 2007). The average pH levels (natural = 5.920; 1989 = 5.923; 1997 = 5.727; 2009 = 5.887), as well as the soil texture measurements recorded in the current study, did not differ significantly between age groups and the natural grassland. These measures were similar to those of the non-degraded soils observed by Oluwole and Sikhalazo (2008) at Tsolwana Nature Reserve (NR) in the Eastern Cape. Tsolwana NR is located ∼45 km northeast of the sample site and is geologically located in the Tarkastad subgroup (Beaufort group; Council for Geoscience, 2021). A decrease in soil pH from extremely degraded to non-degraded soils was observed at Tsolwana NR (Oluwole & Sikhalazo, 2008), whereas no significant differentiation was observed between the sample sites in this study. Similarly to the current study, Aguilera et al. (2013) observed no significant difference between pH or electrical conductivity while investigating changes in soil quality of 10- to 40-year-old abandoned crop fields in the Bolivian Andean Highland Region. This could be an indication of pH levels remaining stable over time at the sampling sites. Additionally, no signs of erosion were observed in the fallow fields located in the current study site. The retention of the field contours and the natural establishment of a mixture of grasses and forbs could have prevented erosion and excessive loss of topsoil following the abandonment of crop farming. In addition to the evident positive effects gained from the retention of old field contours in terms of soil erosion prevention, it was also previously reported that increased soil fertility is observed within the furrows left in old fields (Memiaghe, 2008; Ruwanza, 2017). These furrows could then play a crucial role in native vegetation colonization in the surrounding natural habitat. The colonization by native vegetation types could therefore also have assisted in the recovery of pH and salinity over time in the current study sites.

The estimated mean values of C stock, N stock, C percentage, N percentage, and soil WHC showed an increase when moving from the youngest abandoned field sites to the oldest and then the natural sites (Figure 2). The multivariate linear regression analysis indicated that the C stock, N stock, C percentage, N percentage, and soil WHC values were all positively correlated with age since abandonment ($p < 0.005$; Table 1; Figure S1). These observations could indicate that the old crop fields have already started to revert to their natural conditions, although not completely.

TABLE 1 The multivariate linear regression results assessing the effect of time since abandonment between three old crop field age groups and natural grassland.

Independent variable	Dependent variables	*r*	*p*-Value
Age	Soil bulk density	−0.059	0.855
	pH	0.200	0.533
	TDS	0.383	0.220
	N percentage	0.835	**0.001**
	C percentage	0.847	**0.001**
	N stock	0.785	**0.003**
	C stock	0.756	**0.004**
	WHC	0.895	**0.0001**
	Sand	−0.065	0.841
	Silt	0.150	0.641
	Clay	−0.195	0.543

Note: The Mantel test *r* values and significance values (*p*-value = 0.05) are provided. Significant *p*-values are presented in bold text.
Abbreviations: TDS, total dissolved solids; WHC, water holding capacity.

The trend observed for the WHC estimates in the current study can be linked to denser vegetation levels observed in the natural sites and the gradual natural restoration of vegetation in the fallow fields. The denser vegetation levels will, in turn, provide a larger organic matter component to the soil, decreasing soil compaction and influencing WHC (Hazelton & Murphy, 2007). This is further supported by the higher C percentage, N percentage, C stock, and N stock values observed for the natural sites and the increase of these values with field abandonment age. A significant increase in soil C and a decrease in soil compaction as the age of old crop fields increased were also reported by Shackleton et al. (2013) while assessing old crop fields in the low altitude and high rainfall region of the Wild Coast, Eastern Cape. Vegetation restoration has been linked to increases in C (De Deyn et al., 2011; Yang et al., 2019) and total N (Huang et al., 2020), with higher vegetation diversity levels associated with higher soil C and N levels. The observed difference in C and N levels among the sample sites can also be linked to the difference in vegetation diversity observed between the sites (Yang et al., 2019). It has been reported that different plant groups (e.g., C3 vs. C4 grasses) deposit C and N into the soil at different rates due to greater root biomass and slower root degradation observed in C4 grasses compared to forbs and C3 grasses (Fornara & Tilman, 2008). The observed increased C and N

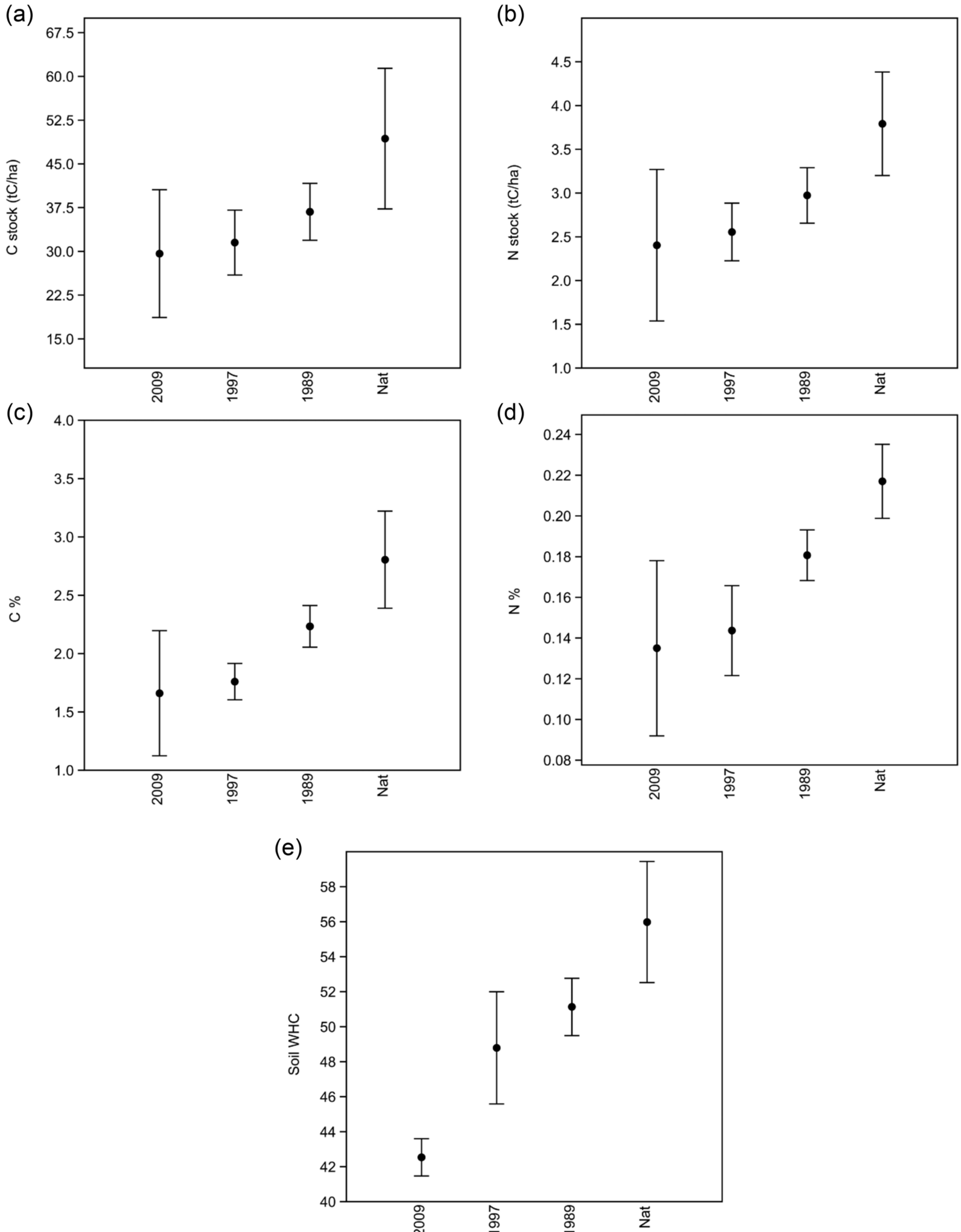

FIGURE 2 The estimated mean values for the five soil characteristics show a significant correlation with age since cropping abandonment. (a) C stock, (b) N stock, (c) C percentage, (d) N percentage, and (e) soil water holding capacity (WHC). A significant difference can be observed in all cases between the youngest sites and the natural sites. The whisker interval represents the 95% confidence interval for the estimate of the mean based on the standard error (Hammer et al., 2001).

estimates can further be related to the presence of sheep that graze these camps on a rotational basis. Livestock is known to contribute positively to C and N levels in the soil through urine and feces (Liebig et al., 2012; Packer, 1988; Southorn & Cattle, 2004). In the long term, total recovery of the current study sites to a natural state will likely not occur for a significant amount of time. Therefore, continued monitoring of this site and other similar sites in the region's agricultural and conservation areas is imperative to ensure proper habitat recovery.

The observed differentiation between the naturally recovered old crop fields and natural sites was further supported

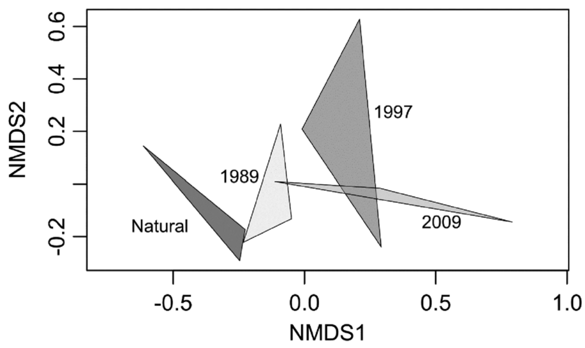

FIGURE 3 The non-metric multidimensional scaling (NMDS) plot is based on Gower's dissimilarity matrix of all soil characteristics from the current study. A change in soil character composition can be observed along the *x*-axis, with the two younger abandoned sites the least similar to the surrounding natural grassland habitat (stress = 0.024; goodness of fit [Gof] = 0.003–0.01).

by the NMDS analysis (Figure 3). Goodness of fit (Gof) values indicate a good fit of the observations on the NMDS plot (Gof values < 0.01), with a stress value of <0.05 (non-metric fit $r^2 = 0.999$; linear fit $r^2 = 0.996$). No overlap was observed between the recovering old crop fields and the natural veld. The old crop fields did, however, show overlap as well as signs of variation within the age groups. It can be seen from the NMDS *x*-axis that there is a progression from the youngest of the recovering crop fields to the natural sites, with the oldest crop field grouping closest to the natural sites. This provided further support for observations from the post-hoc tests performed during the MANOVA analysis.

In conclusion, the results presented here suggest that the WHC, C, and N levels of these recovering old crop fields will only fully recover in another few decades. It is, therefore, important to continuously observe such sites to prevent the establishment of invasive species and promote the colonization of native vegetation. This is especially true for wildlife conservation areas located on old agricultural lands. An increase in abandoned croplands could be seen in the study region due to shifting rainy seasons. This could, in turn, lead to an increase in recovering grassland habitats with a higher resilience toward climate change, as adaptable plant species could dominate these habitats. Further research focusing on how soil health recovery affects vegetation and animal biodiversity are important aspects to also consider when investigating habitat recovery. Such research will further contribute to the information on old crop field habitat recovery in South Africa, providing valuable resources to conservation biologists locally and globally.

AUTHOR CONTRIBUTIONS

Willem Coetzer: Conceptualization; formal analysis; funding acquisition; investigation; methodology, resources; writing–original draft; writing—review and editing. **Kayleigh Coetzer**: Conceptualization; methodology; validation; writing—review and editing.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Elmarie Kotze from the Department of Soil, Crop, and Climate Sciences, University of the Free State, for her advice and guidance during this study. The authors would also like to thank Mr. J. M. Coetzer for providing access to his property and allowing us to conduct our research there. The authors would also like to acknowledge the University of the Free State and the University of Fort Hare for providing the necessary resources and time to do this research. The study was funded by research incentive funding provided to WGC by the Department of Genetics, University of the Free State.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data used for our analyses are provided in Table S1.

ORCID

Willem G. Coetzer https://orcid.org/0000-0003-2189-5539

REFERENCES

Aguilera, J., Motavalli, P., Valdivia, C., & Gonzales, M. A. (2013). Impacts of cultivation and fallow length on soil carbon and nitrogen availability in the Bolivian Andean highland region. *Mountain Research and Development*, *33*(4), 391–403. https://doi.org/10.1659/MRD-JOURNAL-D-12-00077.1

An, H., Zhang, B., Thomas, B. W., Beck, R., Willms, W. D., Li, Y., & Hao, X. (2019). Short term recovery of vegetation and soil after abandoning cultivated mixedgrass prairies in Alberta, Canada. *Catena*, *173*, 321–329. https://doi.org/10.1016/j.catena.2018.10.017

Arévalo, J. R., Fernández-Lugo, S., Reyes-Betancort, J. A., Tejedor, M., Jiménez, C., & Díaz, F. J. (2017). Relationships between soil parameters and vegetation in abandoned terrace fields vs. non-terraced fields in arid lands (Lanzarote, Spain): An opportunity for restoration. *Acta Oecologica*, *85*, 77–84. https://doi.org/10.1016/j.actao.2017.09.014

Beck, H. E., Zimmermann, N. E., Mcvicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data*, *5*(1), 180214. https://doi.org/10.1038/sdata.2018.214

Benhin, J. K. A. (2008). South African crop farming and climate change: An economic assessment of impacts. *Global Environmental Change*, *18*(4), 666–678. https://doi.org/10.1016/j.gloenvcha.2008.06.003

Bhadha, J. H., Capasso, J. M., Khatiwada, R., Swanson, S., & Laborde, C. (2017). Raising soil organic matter content to improve water holding capacity: SI447/Ss661. *EDIS*, *2017*, 5. https://doi.org/10.32473/edis-ss661-2017

Blair, D., Shackleton, C., & Mograbi, P. (2018). Cropland abandonment in South African smallholder communal lands: Land cover change (1950–2010) and farmer perceptions of contributing factors.

Land, *7*(4), 121. https://www.mdpi.com/2073-445X/7/4/121 https://doi.org/10.3390/land7040121

Bradley, B. A., Estes, L. D., Hole, D. G., Holness, S., Oppenheimer, M., Turner, W. R., Beukes, H., Schulze, R. E., Tadross, M. A., & Wilcove, D. S. (2012). Predicting how adaptation to climate change could affect ecological conservation: Secondary impacts of shifting agricultural suitability. *Diversity and Distributions*, *18*(5), 425–437. https://doi.org/10.1111/j.1472-4642.2011.00875.x

Clark, V. R., Barker, N. P., & Mucina, L. (2009). The Sneeuberg: A new centre of floristic endemism on the Great Escarpment, South Africa. *South African Journal of Botany*, *75*(2), 196–238. https://doi.org/10.1016/j.sajb.2008.10.010

Clark, V. R., Barker, N. P., & Mucina, L. (2011). The Great Escarpment of southern Africa: A new frontier for biodiversity exploration. *Biodiversity and Conservation*, *20*(12), 2543–2543. https://doi.org/10.1007/s10531-011-0103-3

Clark, V. R., Dold, A. P., Mcmaster, C., Mcgregor, G., Bredenkamp, C., & Barker, N. P. (2014). Rich sister, poor cousin: Plant diversity and endemism in the Great Winterberg–Amatholes (Great Escarpment, Eastern Cape, South Africa). *South African Journal of Botany*, *92*, 159–174. https://doi.org/10.1016/j.sajb.2014.01.008

Council for Geoscience. (2021). *1:1 000 000 geological data*. https://www.geoscience.org.za/index.php/publication/downloadable-material

De Deyn, G. B., Shiel, R. S., Ostle, N. J., Mcnamara, N. P., Oakley, S., Young, I., Freeman, C., Fenner, N., Quirk, H., & Bardgett, R. D. (2011). Additional carbon sequestration benefits of grassland diversity restoration. *Journal of Applied Ecology*, *48*(3), 600–608. https://doi.org/10.1111/j.1365-2664.2010.01925.x

Dixon, P. (2003). VEGAN, a package of R functions for community ecology. *Journal of Vegetation Science*, *14*(6), 927–930. https://doi.org/10.1111/j.1654-1103.2003.tb02228.x

Dray, S., & Dufour, A.-B. (2007). The ade4 package: Implementing the duality diagram for ecologists. *Journal of Statistical Software*, *22*(4), 1–20. https://10.18637/jss.v022.i04

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302–4315. https://doi.org/10.1002/joc.5086

Fornara, D. A., & Tilman, D. (2008). Plant functional composition influences rates of soil carbon and nitrogen accumulation. *Journal of Ecology*, *96*(2), 314–322. https://doi.org/10.1111/j.1365-2745.2007.01345.x

Geddes, L. S., Lunt, I. D., Smallbone, L. T., & Morgan, J. W. (2011). Old field colonization by native trees and shrubs following land use change: Could this be Victoria's largest example of landscape recovery? *Ecological Management & Restoration*, *12*(1), 31–36. https://doi.org/10.1111/j.1442-8903.2011.00570.x

Gee, G. W., & Bauder, J. W. (1986). Particle-size analysis. In A. Klute (Ed.), *Methods of soil analysis: Part 1* (vol. 5, pp. 383–411). Soil Science Society of America. https://doi.org/10.2136/sssabookser5.1.2ed.c15

Google Earth Pro. (2021). *Leliekloof farm, Chris Hani District, Eastern Cape, RSA (5 May 2020)*. (Version v7.3.3.7786) Maxar Technologies, AfriGIS (Pty) Ltd. and Google. http://www.earth.google.com

Gower, J. C. (1971). A general coefficient of similarity and some of its properties. *Biometrics*, *27*, 857–871. https://doi.org/10.2307/2528823

Gura, I., & Mnkeni, P. N. S. (2019). Crop rotation and residue management effects under no till on the soil quality of a Haplic Cambisol in Alice, Eastern Cape, South Africa. *Geoderma*, *337*, 927–934. https://doi.org/10.1016/j.geoderma.2018.10.042

Hammer, Ø., Harper, D. A., & Ryan, P. D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, *4*(1), 9.

Hazelton, P., & Murphy, B. (2007). *Interpreting soil test results: What do all the numbers mean?* (2nd ed.). CSIRO publishing.

Heydari, M., Zeynali, N., Bazgir, M., Omidipour, R., Kohzadian, M., Sagar, R., & Prevosto, B. (2020). Rapid recovery of the vegetation diversity and soil fertility after cropland abandonment in a semiarid oak ecosystem: An approach based on plant functional groups. *Ecological Engineering*, *155*, 105963. https://doi.org/10.1016/j.ecoleng.2020.105963

Huang, C., Zeng, Y., Wang, L., & Wang, S. (2020). Responses of soil nutrients to vegetation restoration in China. *Regional Environmental Change*, *20*(3), 82. https://doi.org/10.1007/s10113-020-01679-6

Ighodaro, I. D., Lategan, F. S., & Yusuf, S. F. G. (2013). The impact of soil erosion on agricultural potential and performance of Sheshegu community farmers in the Eastern Cape of South Africa. *Journal of Agricultural Science*, *5*(5), 140. https://doi.org/10.5539/jas.v5n5p140

Jacobs, A. J., van Tol, J. J., & Du Preez, C. C. (2018). Farmers perceptions of precision agriculture and the role of agricultural extension: A case study of crop farming in the Schweizer-Reneke region, South Africa. *South African Journal of Agricultural Extension*, *46*(2), 107–118. https://doi.org/10.17159/2413-3221/2018/v46n2a484

Jenkinson, D. S., & Powlson, D. S. (1976). The effects of biocidal treatments on metabolism in soil — V: A method for measuring soil biomass. *Soil Biology and Biochemistry*, *8*(3), 209–213. https://doi.org/10.1016/0038-0717(76)90005-5

Legendre, P., & Legendre, L. (2012). *Numerical ecology*. Elsevier.

Liebig, M. A., Tanaka, D. L., Kronberg, S. L., Scholljegerdes, E. J., & Karn, J. F. (2012). Integrated crops and livestock in central North Dakota, USA: Agroecosystem management to buffer soil change. *Renewable Agriculture and Food Systems*, *27*(2), 115–124. https://doi.org/10.1017/S1742170511000172

Mantel, N. (1967). The detection of disease clustering and a generalized regression approach. *Cancer Research*, *27*, 209–220.

Masibonge, G., Tefera, S., & Mota, L. (2020). Invasion of Euryops floribundus in degraded South African communal grassland: Unpacking the invasion relationship with elevation, soil properties, the quality and quantity of the herbaceous layer. *African Journal of Ecology*, *58*(1), 69–79. https://doi.org/10.1111/aje.12642

Memiaghe, H. R. (2008). *Old field restoration: Vegetation response to soil changes and restoration efforts in the Western Cape lowlands*. Stellenbosch University.

Miller, W., Armstrong, R., & De Wit, M. J. (2016). Geology and U/PB geochronology of the Gamtoos Complex and lower Paleozoic Table Mountain Group, Cape Fold Belt, Eastern Cape, South Africa. *South African Journal of Geology*, *119*(1), 147–170. https://doi.org/10.2113/gssajg.119.1.147

Mills, A., & Fey, M. (2004). Transformation of thicket to savanna reduces soil quality in the Eastern Cape, South Africa. *Plant and Soil*, *265*(1), 153–163. https://doi.org/10.1007/s11104-005-0534-2

Mucina, L., & Rutherford, M. C. (2006). *The vegetation of South Africa, Lesotho and Swaziland*. South African National Biodiversity Institute.

Mupambwa, H., & Wakindiki, I. (2012). Winter cover crops effects on soil strength, infiltration and water retention in a sandy loam Oakleaf soil in Eastern Cape, South Africa. *South African Journal of Plant* *and Soil*, *29*(3–4), 121–126. https://doi.org/10.1080/02571862.2012.722697

Muzangwa, L., Mnkeni, P. N. S., & Chiduza, C. (2021). Soil C sequestration and CO2 fluxes under maize-based conservation agriculture systems in the Eastern Cape, South Africa. *South African Journal of Plant and Soil*, *38*(3), 276–283.

Nelson, D. W., & Sommers, L. E. (1983). Total carbon, organic carbon, and organic matter. In A. Page (Ed.), *Methods of soil analysis* (pp. 539–579). American Society of Agronomy. https://doi.org/10.2134/agronmonogr9.2.2ed.c29

Njaimwe, A. N., Mnkeni, P. N., Muchaonyerwa, P., Chiduza, C., & Wakindiki, I. I. (2018). Sensitivity of selected chemical and biological soil quality parameters to tillage and rotational cover cropping at the Zanyokwe Irrigation Scheme, South Africa. *South African Journal of Plant and Soil*, *35*(5), 321–328. https://doi.org/10.1080/02571862.2018.1446225

Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Stevens, M. H. H., Oksanen, M. J., & Suggests, M. (2007). The vegan package. *Community Ecology Package*, *10*(631–637), 719.

Oluwole, F. A., & Sikhalazo, D. (2008). Land degradation evaluation in a game reserve in Eastern Cape of South Africa: Soil properties and vegetation cover. *Scientific Research and Essays*, *3*(3), 111–119.

Packer, I. J. (1988). *The effects of grazing on soils and productivity: A review* (Technical Report no. 4). Soil Conservation Service of New South Wales, Sydney.

Pavoine, S., Vallet, J., Dufour, A.-B., Gachet, S., & Daniel, H. (2009). On the challenge of treating various types of variables: Application for improving the measurement of functional diversity. *Oikos*, *118*(3), 391–402. https://doi.org/10.1111/j.1600-0706.2008.16668.x

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.r-project.org

Rey Benayas, J. M., Martins, A., Nicolau, J. M., & Schulz, J. J. (2007). Abandonment of agricultural land: An overview of drivers and consequences. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *2*(57), 1–14.

Ruwanza, S. (2017). Furrows as centers of restoration in old fields of Renosterveld, South Africa. *Ecological Restoration*, *35*(4), 289–291. https://doi.org/10.3368/er.35.4.289

Shackleton, R., Shackleton, C., Shackleton, S., & Gambiza, J. (2013). Deagrarianisation and forest revegetation in a biodiversity hotspot on the Wild Coast, South Africa. *PLoS One*, *8*(10), e76939. https://doi.org/10.1371/journal.pone.0076939

Southorn, N., & Cattle, S. (2004). The dynamics of soil quality in livestock grazing systems. In *SuperSoil 2004: 3rd Australian New Zealand soils conference* (pp. 1–7). University of Sydney.

Suich, H., & Boardman, J. (2017). Wheat growing and changing farming systems in South African dryland margins: The case of the Sneeuberg, South Africa. *Land Degradation & Development*, *28*(1), 57–64. https://doi.org/10.1002/ldr.2543

Valkó, O., Deák, B., Török, P., Kelemen, A., Miglécz, T., & Tóthmérész, B. (2017). Filling up the gaps—Passive restoration does work on linear landscape elements. *Ecological Engineering*, *102*, 501–508. https://doi.org/10.1016/j.ecoleng.2017.02.024

van Rooyen, M. W., Henstock, R., van Rooyen, N., & van der Merwe, H. (2010). Plant diversity and flowering displays on old fields in the arid Namaqua National Park, South Africa. *Koedoe*, *52(1)*, a1004. https://doi.org/10.4102/koedoe.v52i1.1004

Wang, H., Shu, D., Liu, D., Liu, S., Deng, N., & An, S. (2020). Passive and active ecological restoration strategies for abandoned farmland leads to shifts in potential soil nitrogen loss by denitrification and soil denitrifying microbes. *Land Degradation & Development*, *31*(9), 1086–1098.

Yang, Y., Tilman, D., Furey, G., & Lehman, C. (2019). Soil carbon sequestration accelerated by restoration of grassland biodiversity. *Nature Communications*, *10*(1), 718. https://10.1038/s41467-019-08636-w

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Coetzer, W. G., & Coetzer, K. (2023). Natural recovery of old crop fields in a South African grassland biome. *Agronomy Journal*, *115*, 2859–2866. https://doi.org/10.1002/agj2.21365