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Climate Resilience in Rural Agriculture: A Case Study of Smallholder Farmers in Ndwedwe, KwaZulu-Natal, South Africa

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Abstract

Erratic rainfall, rising temperatures, and soil degradation have contributed to declining yields, particularly in staple crops such as maize, which are essential for household food security. This study quantitatively assessed climate resilience among smallholder farmers in Ndwedwe, KwaZulu-Natal, using a structured survey of 111 participants to collect data on farming experience, soil degradation, crop and livestock productivity, income and adaptive strategies. Analysis revealed that 79.2% of respondents had more than five years of farming experience. Over half (56.8%) reported soil degradation and 71.1% indicated shifting cultivation fields due to persistent poor crop performance. Nearly half (45%) reported reductions in crop yields, and 45.9% applied additional fertilizer to mitigate losses. Notably, 91% of respondents reported negative impacts on household food security and income reductions (83%). The results of the multivariable regression analysis show that households that experienced soil degradation and decreasing crop yields were more likely to be food insecure than households that were able to meet their food security needs. In contrast, the respondents findings revealed that farming experience, being assisted by extension services, and using an integrated adaptation strategy was positively correlated with food security and households. The South African Climate Resilience Index indicates that approximately 38% of the households sampled had low levels of resilience, 44% of households had moderate levels of resilience and 18% had high levels of resilience; male-headed households and those who have farmed for longer periods generally achieved higher resilience. The results of this research suggest that targeted interventions are immediately needed to promote education on sustainable soil management, climate-smart practices and institutional support that builds adaptive capacity and secure the livelihood of rural residents in Ndwedwe, South Africa.

Keywords: Adaptation, climate resilience, food security, smallholder farmers, soil degradation

1. Introduction

Climate change is increasingly recognized as one of the most urgent and complex global challenges of the twenty-first century, with far-reaching implications for agriculture, food security, and rural livelihoods (Rayhan et al., 2023). Agriculture is particularly sensitive to climatic variability and remains the principal source of income, employment, and subsistence for rural populations in many developing regions. Smallholder farmers, who often lack access to adequate resources, technology, and institutional support, are disproportionately affected by climate-induced shocks such as droughts, floods, rising temperatures, and erratic rainfall patterns. These climatic stressors undermine agricultural productivity, threaten food security, and exacerbate poverty in already fragile rural economies (Zenda, 2024).

Against this backdrop, the present study examines how farmers in the study area, experience and respond to climate variability. Specifically, it explores the adaptive strategies employed to enhance resilience, as well as the institutional and structural factors that either enable or constrain their adaptive capacity. This study contributes to the growing body of scholarship on rural climate resilience in South Africa and provides practical insights to inform policy, agricultural extension, and local development planning aimed at strengthening rural communities in the face of climate change.

2. Background / Literature Review

In South Africa, agriculture plays a dual role as both a key driver of economic growth and a critical source of livelihood for rural households. However, the sector faces mounting challenges arising from climate variability, land degradation, and water scarcity (Meyer et al., 2025). Zwane and Montmasson-Clair (2016) further identify that climate change poses several risks to agriculture in South Africa. These include changing precipitation patterns, increasing evaporation rates, rising temperatures, more pests and disease, shifted geographic distributions of pests and diseases, decreased yields and changes in the optimal geographic regions for agriculture. As mentioned in the South African Department of Agriculture, Forestry and Fisheries, these numerous threats to agriculture in South Africa are all interlinked with climate change, making agriculture in South Africa generally vulnerable to climate change. With regard to increasing food insecurity, FAO (2010) indicates climate change and the associated risks also compound farmers' challenges, with smallholder farmers being disproportionately affected by climate change (Harvey et al., 2014). The DAFF also indicated that smallholder farmers in South Africa have encountered numerous challenges when coping with the impacts of various climate-related disasters.

Previous research focused on different individual measures farmers can take to adapt at the farm level (Chinwe 2010; Dang et al., 2012). However, not all strategies available to different farmers are well-documented (Shrestha et al. 2018), and this restricts the options of strategies that are available to all farmers as indicated. Therefore, it is necessary to conduct research on adaptation strategies to assist farmers who may be faced with various forms of natural disasters, such as floods and/or droughts, which place them at risk of experiencing food insecurity (Elum et al. 2017). Adaptation, within the context of this research, is defined as a mechanism or process that occurs between different components or parts of a system (e.g. household, community, group, sector, region, or country), which helps the system cope, adjust or better survive conditions, stress, hazards, risk or opportunities that result in changes to the system (Smit & Wandel 2006). In terms of climate change, adaptation strategies are the practices practised by smallholder farmers to adapt or mitigate the impacts resulting from climate change/variability (Kuwornu et al. 2013). The environmental factors are the only few variables that would factor into the consideration of the selection of crops or livestock raised by a farmer (Maddison, 2007).

According to Hassan and Nhemachena (2008), if farmers can effectively plan and react to climate change, they will be able to limit the amount of damage that will result from it. Consequently, by analyzing climate change adaptation strategies therefore will also help farmers to identify how to adapt to many of the adverse impacts of climate change (Hassan & Nhemachena, 2008). Furthermore, these strategies are essential for protecting the lives of the farmers and ensuring food security (Bryan et al, 2009).

Smallholder farmers in provinces such as KwaZulu-Natal are particularly vulnerable due to their reliance on rain-fed agriculture, limited access to climate-smart technologies, and restricted adaptive capacity (Zenda, 2024; Maziya et al., 2024). Within this context, Ndwedwe, a rural municipality in KwaZulu-Natal serves as a representative case where climate change directly undermines smallholder farmers' capacity to sustain production and secure household livelihoods.

Despite these constraints, rural farmers are not passive recipients of climatic impacts. Many actively draw on indigenous knowledge systems, adaptive practices, and innovative strategies to cope with changing environmental conditions (Ubisi et al., 2019). The concept of climate resilience defined as the capacity to anticipate, absorb, adapt to, and recover from climate-related shocks while maintaining or improving livelihoods has therefore become central to contemporary agricultural and development discourse (Dale, 2018). Strengthening climate resilience is critical not only for sustaining food production but also for ensuring the long-term sustainability of rural development initiatives.

Ziervogel et al. (2022) explain that climate resilience is increasingly conceptualized as a system's capacity to anticipate, absorb, adapt to, and recover from climate shocks while sustaining or improving livelihoods. They note that contemporary frameworks typically integrate exposure, vulnerability, and adaptive capacity, emphasizing that resilience emerges from the dynamic interactions among social, economic, and environmental factors within complex socio-ecological systems.

To operationalize these multidimensional constructs, researchers have developed quantitative resilience indices, which combine multiple indicators into a single metric. Examples include the Market Systems Resilience Index and the Social Vulnerability Index, both of which integrate environmental, socio-economic, and institutional dimensions. Seyisi et al. (2023) argue, however, that many existing indices are generalized and may not fully capture local agro-ecological and socio-institutional realities, underscoring the importance of context-sensitive, locally tailored resilience measures.

In South Africa, smallholder farmers are particularly vulnerable due to reliance on rain-fed agriculture, limited access to climate-smart technologies, and constrained adaptive capacity (Zenda, 2024; Maziya et al., 2024). While prior research has explored vulnerability patterns and adaptive strategies, few studies have developed composite indices specifically calibrated for local smallholder systems. This study addresses this gap by developing a Climate Resilience Index (CRI) for Ndwedwe, KwaZulu-Natal, integrating environmental, socio-economic, and institutional dimensions to provide a quantitative, context-sensitive measure of household resilience and identify key drivers of adaptive capacity.

3. Methodology

3.1. Research Design

This study adopted a quantitative research approach within the framework of rural agricultural research. The case study design was selected because it allowed for an in-depth, context-specific exploration of how smallholder farmers in Ndwedwe understood, experienced, and responded to climate variability and change (The Role of Context in Qualitative Case Study Research: Understanding Service Innovation, 2022). The quantitative method employed structured numerical data to systematically measure patterns, identify trends, and analyze relationships among key variables. This study employed a quantitative approach to examine climate resilience as a multidimensional phenomenon, encompassing environmental, socio-economic, and institutional factors. By focusing on measurable indicators across these dimensions, the method enabled systematic analysis of patterns, trends, and relationships, ensuring robust, reliable, and evidence-based findings that can inform effective adaptation strategies.

3.2 Study Area

The study was conducted in Ndwedwe, KwaZulu-Natal, South Africa, focusing on rural villages where smallholder, predominantly rain-fed agriculture was practiced. Fieldwork took place at farm homesteads. The setting was characterized by small farm sizes, mixed cropping and small livestock holdings, limited irrigation infrastructure, and variable access to agricultural extension services, features that made Ndwedwe a suitable site for investigating household-level climate resilience.

3.3 Study Population

The target population comprised all smallholder farming households within the selected Ndwedwe study area whose primary livelihood included crop and/or livestock production (N = 200). A relatively large proportion of the population was purposively selected to capture a diverse range of experiences and characteristics within the smallholder farming community, ensuring inclusion of key subgroups—such as household heads or primary decision-makers aged 18 years or older who had been actively engaged in farming for at least the previous 12 months—thereby enabling detailed comparison of patterns and trends within the sample. Exclusion criteria included: (1) commercial farms that did not meet the smallholder definition, (2) households not engaged in agricultural activities in the past year, and (3) individuals under 18 years of age.

3.4 Sampling and Sample Size

A total of 111 farmers were sampled from the population of 200 (sample fraction = 111 / 200 = 0.55, i.e., 55% of the population). This relatively large fraction was intentionally chosen to increase precision and representativeness in a small, finite population and to allow robust subgroup analyses, for example by gender, farm size, or age group.

Purposive (judgmental) sampling was employed for this case study because the research aimed to obtain information-rich cases that illustrated different experiences of climate risk and resilience in Ndwedwe. This approach enabled the inclusion of farmers with varying exposure, adaptive behaviors, demographic characteristics, and institutional linkages, allowing patterns and mechanisms of resilience to be compared and explained. This approach was appropriate for capturing variation within the defined rural farming systems due to the context-specific and exploratory nature of the project that was focused on developing and testing a Climate Resilience Index (CRI). However, the sample design choice was non-probabilistic; therefore, rigorous statistical generalization could only occur within the Ndwedwe study area. The internal validity of the findings as measured by the high sampling fraction adds to confidence in the association between what was observed among the case-study population, but the estimated proportions and regression coefficients are not representative of all smallholder farmers in KwaZulu-Natal. Instead, the results should be seen as supporting analytical generalization and theory-building and should be considered transferable to smallholder contexts that are similar in nature; however, to make inferences at a broader population level, further investigations would need to use a probability-based sampling design in the studies undertaken in KwaZulu-Natal.

3.5 Instrument Design, Data Collection and Analysis

A structured survey was developed using established frameworks for rural livelihoods and climate resilience. Data were collected through the use of four sections covering principles such as socio-demographic characteristics, production and farming systems, climatic exposures and adapting practices, and access to support mechanisms. Data was collected through four types of questions: yes/no answers, Likert-type scales (1 = strongly disagree to 5 = strongly agree) and frequency-based measures. Data were collected through face-to-face interviews conducted at farm homesteads to ensure clarity and completeness. Primary data were obtained from 111 purposively selected farmers in Ndwedwe using a structured questionnaire. Secondary data, including meteorological records and agricultural reports, were reviewed to contextualize primary findings. Quantitative data from the questionnaires were coded and analyzed using SPSS. Descriptive statistics were used to summaries farmer characteristics and adaptation practices. Chi-square tests were used to examine associations between farming experience, soil degradation, adaptation strategies, production output, and household income. A multivariable binary logistic regression models were estimated. Statistical significance was set at $p < 0.05$.

3.6 Operationalization of Variables and Climate Resilience Index

The operationalization of the variable climate resilience was through the construction of a composite index referred to as the Climate Resilience Index. This Climate Resilience Index was composed of three dimensions: environmental, socio-economic, and institutional. The ecological dimension included ground-based experiences of soil degradation, decreased crop yield, and decreased livestock production. The socio-economic dimension included years of farming experience, stability of household income, and food security of households. The institutional dimension included access to agricultural extension services, access to climate and weather information, and institutional supports available. To ensure comparability across variables measured on different scales, indicators were normalized using min–max scaling as $X' = \frac{X - X_{min}}{X_{max} - X_{min}}$, where X represents the observed value, and X_{min}, X_{max} represent the minimum and maximum values in the sample.

The conversion of values for all measures to a scale between 0–1, was done separately for each dimension. The dimension scores were created by averaging the normalized indicators in each respective dimension together. The final Community Resilience Index (CRI) was provided by averaging together the three dimension scores through the following formula: CRI $= \frac{D_{env} + D_{soc} + D_{ins}}{3}$ using equal weight for each of the three dimensions. The robustness of the results was evaluated through a "leave one out" analysis, where the CRI scores were calculated again, removing one indicator from each iteration, which allowed for an estimate of how stable the CRI was across multiple runs. The classifications of household resiliency remained stable, with less than 5% of households changing classification after this sensitivity analysis. The classifications of household resiliency (low, medium, high) were generated utilizing thresholds established through an analysis of the distribution of the CRI score within the sample. The thresholds established were <0.40 for low, 0.40 – 0.60 for medium, and >0.60 for high to adequately capture and reflect meaningful differences across the lower, middle, and upper portions of the observed resilience range. This approach was established to maintain transparency in the assignment of different weights, to avoid potential bias in a subjective manner of establishing different weights and provide an avenue for replicating the results if a strong theoretical framework did not prove sufficient enough to justify unequal weights.

3.7 Pretesting, Reliability and Validity

Prior to the full-scale data collection, the questionnaire was pretested with 10 smallholder farmers from an adjacent rural area not included in the final sample. The questionnaire was modified slightly to enhance clarity and contextual relevancy. Reliability was measured using Cronbach's alpha, with all multi-item constructs measuring greater than 0.70, which is an acceptable level of reliability. Predictive validity was assessed by examining the relationship between CRI scores and key livelihood outcomes, including food insecurity and production decline. As expected, lower CRI scores were significantly associated with higher vulnerability outcomes ($p < 0.05$), supporting the index's predictive validity.

3.8 Ethical Considerations

The study adhered to established ethical standards. Informed consent was obtained from all participants, participation was voluntary, and respondents could withdraw at any time. No personal identifiers were recorded, and all data were securely stored. Findings are reported in aggregate to ensure confidentiality.

3.9 Assumptions and Limitations

This study assumed that respondents provided accurate and truthful information, that the purposive sample was adequately representative of smallholder farmers in Ndwedwe, and that the selected indicators effectively reflected the multidimensional aspects of climate resilience. Nevertheless, the findings are constrained by the case-specific focus, potential sampling bias, and the cross-sectional design, which limit both generalizability and causal interpretation. Despite these limitations, the study offers robust, contextually grounded insights that advance understanding of rural climate resilience and inform adaptive policy and practice in South Africa.

4. Results

4.1. Distribution of Farming Experience among Smallholder Farmers in Ndwedwe

The results presented in Fig. 1 illustrate considerable variation in farming experience among the surveyed participants. Out of 111 respondents, the majority (30.6%, n = 34) had been engaged in farming for more than 5 years but less than 10 years. Close to one-quarter of participants (24.3%, n = 27) reported farming experience between 10 and 20 years, with an equal proportion (24.3%, n = 27) indicating more than 20 years of experience. Only 16.2% (n = 18) had less than 5 years of farming experience, and a small proportion (4.5%, n = 5) did not provide a response.

There was a one-way analysis of variance (ANOVA) performed to see differences in Climate Resiliency Index (CRI) score means among four groups of farmers by years of farming. A total of 111 surveys were used for this analysis. There were 18, 34, 27, and 27 subjects in the four farmer groups with <5, 5 - 10, 10 – 15, and >15 years of farming experience, respectively. There was an overall difference in CRI scores between the years of experience groups for farmers, $F(3, 107) = 4.21$, $p = 0.008$, $\eta^2 = 0.11$, which showed approximately 11% of the variance in CRI scores can be explained by the differences in years of farming experiences. The Tukey HSD post-hoc test did show that CRI scores were significantly higher for farmers with >10 years of farming experience than they were for farmers with <5 years of farming experience (Mean Difference of 0.13, 95% CI: 0.02 - 0.24, $p < 0.05$). Overall, the results of this study indicate an overall positive effect of increasing years of farming experience upon the climate resiliency of households in the Ndwedwe community.

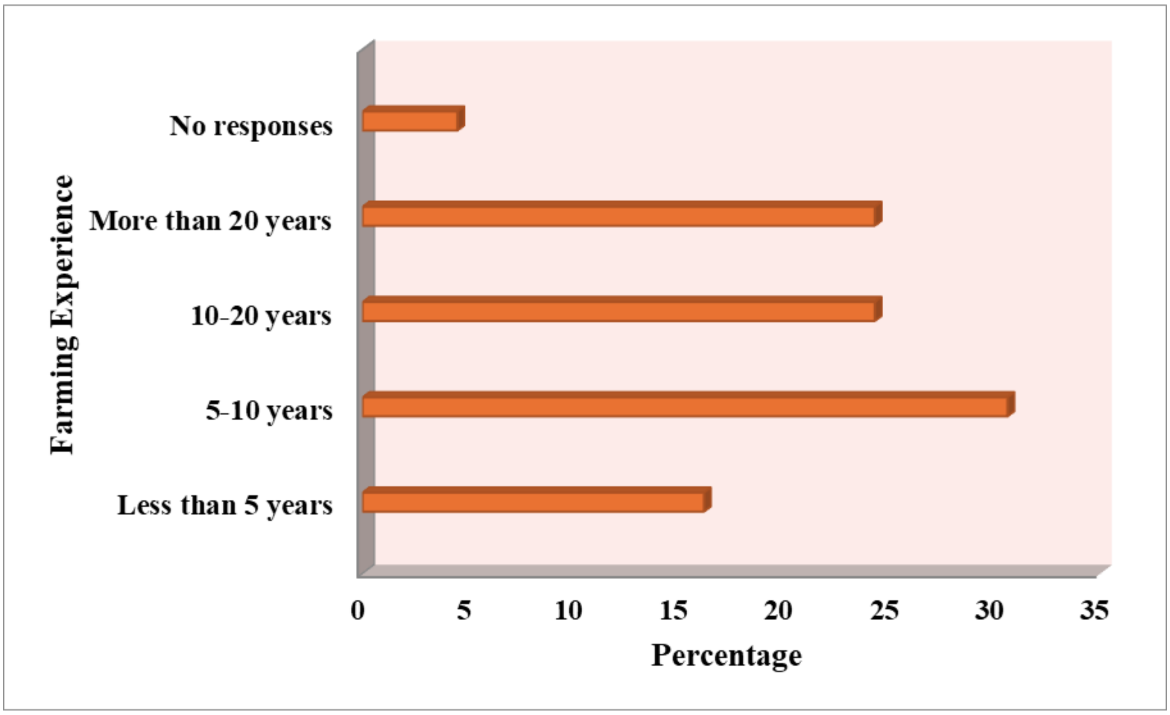

Figure 1. Distribution of Farming Experience among Smallholder Farmers in Ndwedwe

4.2. Perceptions of the Causes of Climate Change

The distribution of responses regarding perceived causes of climate variability and change, as presented in Tab. 1, reveals a predominance of uncertainty among the surveyed farmers. A majority of participants (56.8%, n = 63) reported that they did not know the causes of climate change, indicating limited awareness or understanding of the underlying drivers of climatic shifts. A smaller proportion attributed climate variability to human activities (10.8%, n = 12) or to natural processes associated with climate change (7.2%, n = 8). Notably, 21.6% (n = 24) of respondents recognized both human and natural factors as contributing to climate change. Cross-tabulated CRI (low/moderate/high) climate change awareness with Chi-square tests. The results demonstrated a significant relationship between awareness of climate change and resilience ($\chi^2(6)=13.6$, $p=0.034$, Cramér's $V=0.22$). Farmers who indicated awareness of both man-made and natural causes of climate change were more likely to express building a high level of resilience (32%) than those farmers who responded "don't know" (12%) - note this shows that understanding climate contributes to resilience building.

These findings suggest that while some farmers possess a nuanced understanding of the multiple drivers of climate variability, over half of the respondents lack clarity on the issue. This has important implications for adaptation and resilience strategies, as limited awareness of causative factors may influence perceptions of risk, adoption of climate-smart practices, and engagement with extension services or government support programs. The recognition by some farmers of both anthropogenic and natural causes reflects an emerging awareness that aligns with scientific understanding, which could serve as a foundation for targeted awareness-raising and capacity-building interventions in rural agricultural communities. Overall, the results underscore the need for context-specific climate education and knowledge dissemination to enhance smallholder farmers' capacity to anticipate, respond to, and adapt effectively to climate stressors in Ndwedwe.

Table 1. The Causes of Climate Change in Ndwedwe

Factor	Frequency	Percentage
Climate change	8	7,2
Human beings	12	10,8
Both	24	21,6
Do not know	63	56,8
Total	**107**	**96,4**
No responses	4	3,6
Total	**111**	**100**

4.3. Primary Causes of Declining Agricultural Productivity

The results presented in Fig. 2 reveal that the majority of respondents attributed declining agricultural productivity to poor crop or animal performance, cited by 71.1% (n = 79) of the farmers. This finding underscores the centrality of biophysical factors in shaping farmers' perceptions of agricultural challenges in Ndwedwe. The prominence of this response suggests that most farmers directly link productivity losses to observable declines in yields, livestock health, or production efficiency, rather than to broader environmental or structural drivers.

A smaller proportion of respondents (13.5%, n = 15) identified land size as a key constraint, reflecting the challenges of land fragmentation and limited arable land availability in rural settings. Reduced plot sizes may exacerbate over-cultivation and soil degradation, further constraining productivity. Similarly, changes in soil fertility were mentioned by 9.0% (n = 10) of participants, indicating an awareness of declining soil quality as a factor influencing agricultural output.

Interestingly, only 1.8% (n = 2) of respondents explicitly attributed poor productivity to climate change. This low figure suggests a limited direct recognition of climate change as an underlying cause, despite its well-documented influence on rainfall variability, temperature shifts, and pest prevalence in KwaZulu-Natal. Instead, farmers appear to interpret the effects of climate variability through immediate, tangible outcomes such as crop failure or poor livestock performance, rather than abstract climatic trends.

Overall, these results highlight a critical perceptual gap between scientific understandings of climate-induced agricultural risks and farmers' locally grounded interpretations of productivity decline. This suggests that targeted awareness and capacity-building interventions are needed to strengthen farmers' understanding of the indirect pathways through which climate change affects soil fertility, land productivity, and crop-livestock systems. Such insights are vital for designing effective adaptation and resilience strategies within smallholder agricultural contexts.

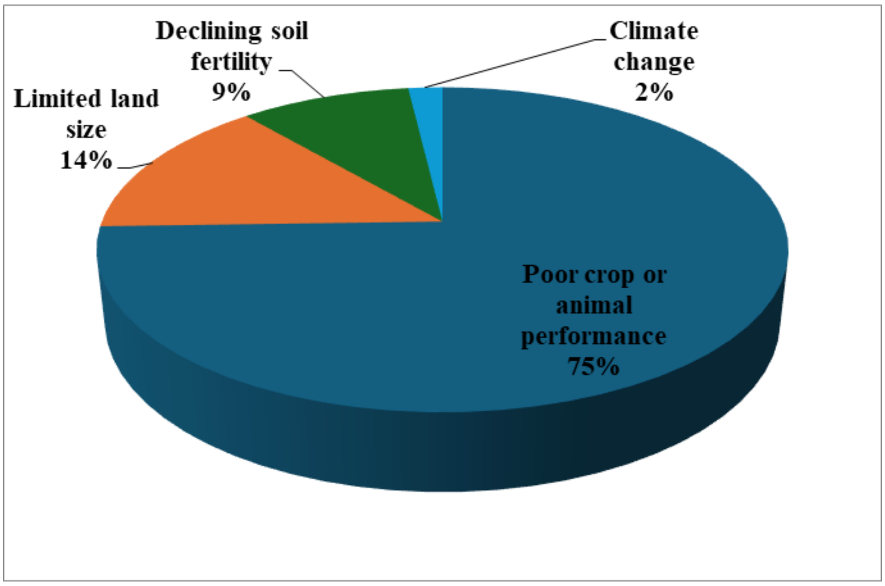

Figure 2. Perceptions of the Primary Causes of Declining Agricultural Productivity

4.4. Impacts of Climate Variability on Agricultural Productivity

The results presented in Table 2 indicate that climate variability had a significant negative effect on both crop and livestock production among smallholder farmers in Ndwedwe. Nearly half of the respondents (45%, n = 50) reported experiencing reduced crop yields as the primary impact of changing climatic conditions. A smaller but notable proportion of respondents (17.1%, n = 19) indicated reduced animal production as the main consequence of climate variability. This reduction likely reflects the combined effects of limited water availability, declining pasture quality, and increased disease prevalence, which collectively undermine livestock health and productivity.

Furthermore, more than a quarter of the respondents (27.9%, n= 31) reported that both crop and animal production had declined simultaneously, underscoring the interconnected vulnerability of mixed farming systems. This dual impact suggests that climate-related shocks, such as drought or extreme heat, do not occur in isolation but rather affect entire household production systems, thereby amplifying livelihood insecurity and food system fragility.

The overall pattern of responses demonstrates that agricultural productivity in Ndwedwe is highly sensitive to climate variability, with most farmers perceiving tangible declines in output across multiple livelihood components. The relatively high proportion of farmers citing reduced crop yields suggests that rain-fed crop systems remain particularly vulnerable, while the concurrent decline in livestock performance points to broader ecological and resource stress.

These findings emphasize the urgent need for integrated climate adaptation strategies including improved water management, climate-smart crop varieties, and resilient livestock management practices to strengthen smallholder resilience and safeguard household food security in climate-stressed rural settings.

Table 2. Effects of Climate Variability on Crop and Livestock Production

Issues	Frequency	Percentage
Reduced crop yields	50	45
Reduced animal production	19	17,1
Both	31	27,9
Total	100	90,1
No responses	11	9,9
Total	**111**	**100**

4.5. Strategies Adopted by Respondents to Manage Soil Fertility and Grazing

The results in Table 3 illustrate the strategies adopted by respondents to address the challenges under study. A majority of respondents (45.9%) indicated that they apply more fertilizer as a primary strategy, highlighting the reliance on chemical inputs to maintain soil fertility and crop productivity. A smaller proportion (10.8%) reported using grazing camp rotation, suggesting that rotational grazing as a land management strategy is less commonly practiced among the surveyed population. Interestingly, 15.3% of respondents employ both strategies, indicating a combined approach to enhance land productivity and sustainability. Notably, 23.4% of respondents reported using neither strategy, which may reflect either constraints in resources, knowledge gaps, or alternative approaches not captured in this survey. An independent-samples t-test showed that farmers applying both strategies had significantly higher CRI scores (mean=0.53, SD=0.14) than those applying none (mean=0.38, SD=0.16), $t(64)=3.18$, $p=0.002$, Cohen's $d=0.97$, indicating that integrated land management practices contribute to higher climate resilience.

Overall, the findings suggest that while fertilizer application remains the dominant strategy, there is a significant portion of respondents exploring integrated approaches or not adopting these specific strategies, emphasizing the need for targeted interventions and capacity-building to promote sustainable land management practices.

Table 3. Approaches to Enhance Crop and Livestock Productivity

Strategy	Frequency	Percentage
Apply more fertilizer	51	45,9
Grazing camp rotation	12	10,8
Both	17	15,3
None of the above	26	23,4
Total	**106**	**95,5**
No responses	5	4,5
Total	**111**	**100**

4.6. Impact of Soil Degradation on Household Incomes

The results presented in Fig. 3 highlight respondents' perceptions of the impact of soil degradation on household incomes. A substantial majority of respondents (83%) reported that soil degradation negatively affects their income, indicating a strong recognition of the economic consequences of declining soil fertility and land productivity. Conversely, 15% of respondents perceived that soil degradation does not impact their income, which may reflect variations in livelihood strategies, access to alternative income sources, or differing levels of awareness regarding soil-related productivity losses. Notably, 13% of respondents did not answer the question, which could suggest uncertainty or a lack of experience with the issue.

Overall, these findings underscore the critical link between soil health and household economic well-being, highlighting the importance of interventions aimed at sustainable land management and income protection for communities affected by soil degradation.

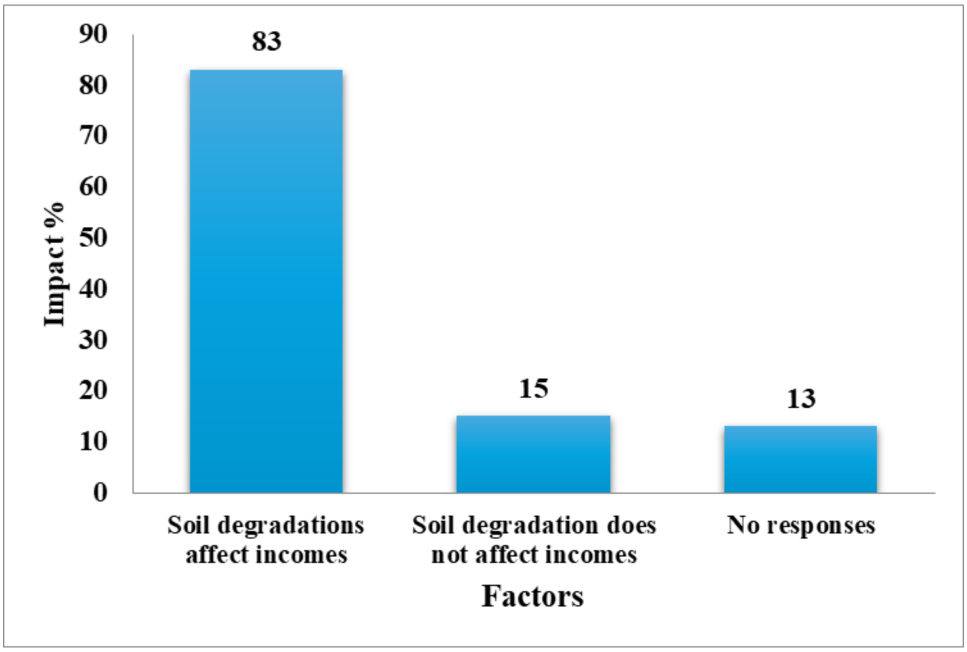

Figure 3. Impact of Soil Degradation on Household Income

4.7. Inferential Analysis

Pearson Chi-square tests were conducted to examine associations between key variables related to climate resilience. A significant association was observed between soil degradation and reduced production output ($p < 0.05$), indicating that farmers experiencing soil degradation were more likely to report production declines. However, no statistically significant association was found between soil degradation and household income reduction ($\chi^2(1) = 1.17$, $p = 0.28$). The absence of statistical significance may reflect reduced variability in income reduction responses, limiting discriminatory power in the model. Although more experienced farmers were descriptively more likely to adopt mitigation strategies, these relationships were not statistically significant at the 5% level.

Food insecurity was the outcome variable in a multivariable logistic regression model using crop loss, livestock loss, length of time spent farming and soil degradation as predictor variables. The model did demonstrate statistical significance ($\chi^2(4)=28.7$, $p<0.001$, Nagelkerke $R^2=0.28$) and showed no evidence of multicollinearity (VIF<2 for all predictor variables).

Table 4. Multivariable Logistic Regression Analysis of Predictors of Food Insecurity

Variable	Odds ratio	95% CI	p-value
Crop decline	2.3	1.2-4.4	0.015
Livestock decline	1.8	0.9-3.5	0.08
Farming experience> 10 years	0.6	0.3-1.2	0.12
Soil degradation	2.7	1.4-5.1	0.003

Overall, those farmers that had either a decline in their crops or degradation of their soil were significantly more likely to report themselves as food insecure, thus demonstrating the significant value of managing the effects of climate on farming production is crucial to securing a farmers' ability to be resilient to outside influences or activities on their farm. Soil degradation and production decline were positively associated with food insecurity, although not all predictors reached statistical significance. A separate model using income reduction as the outcome could not be reliably estimated due to the very high prevalence of income loss, resulting in quasi-complete separation (Tab 4).

4.8 Climate Resilience Index (CRI)

The climate resilience index (CRI) was calculated for all households by combining normalized indicators in the environment, socio-economic and institutional dimensions through equal weighting of each dimension. CRIs ranged from 0.12 to 0.81, with a mean CRI of 0.46 and a standard deviation of 0.17. Based on the defined thresholds; (i) 38% of households had low resilience with a CRI of < 0.40, (ii) 44% of households had moderate resilience with a CRI between 0.40-0.60, and (iii) 18% of households had high resilience with a CRI of > 0.60. The mean scores on each dimension; socio-economic were 0.52, institutional were 0.45 and environmental were 0.41. Subgroup analysis using independent-samples t-tests showed significant differences in resilience. Male-headed households had a higher mean CRI score than female-headed households (0.49 vs. 0.41). Households with more than 10 years of farm experience were more resilient (0.52) than those with less than 5 years of farm experience (0.39). Access to extension services was also significantly related to resilience (mean CRI 0.56 with access compared to 0.38 without access, $p<0.05$). A multiple linear regression analysis was performed with the CRI as the dependent variable and gender of household head, years of farming experience, access to extension services and the adoption of adaptation strategies as independent variables. The model was statistically significant ($F(4,106)=13.8$, $p<0.001$; Adjusted $R^2=0.34$).

Table 5. Climate Resilience Index (CRI) Among Farming Households

Variable	B	95% CI	p-value
Male headed household	0.08	0.02-0.14	0.011
Farming experience> 10 years	0.09	0.02-0.16	0.012
Access to extension services	0.14	0.06-0.22	0.001
Adoption of both methods	0.10	0.03-0.17	0.007

Households led by males, with greater farming experience, access to extension services, and employing integrated strategies had significantly higher resilience scores. These findings highlight the multidimensional determinants of climate resilience at the household level in Ndwedwe. The CRI demonstrated expected associations with key resilience determinants, including farming experience, access to extension services and adoption of integrated adaptation strategies, providing evidence of construct validity (Table 5).

5. Discussion

The results collectively demonstrate the complex interplay between farmers' experience, perceptions, and adaptive strategies in response to soil degradation and climate variability in Ndwedwe. The predominance of respondents with more than five years of farming experience suggests a deep familiarity with local agro-ecological dynamics and adaptive knowledge accumulated through prolonged exposure to climatic stressors. Similar findings by Nhamo et al. (2023) and Shikwambana et al. (2022) affirm that farming experience enhances farmers' adaptive capacity, influencing the adoption of resilient practices such as crop diversification, soil conservation, and water management.

This interpretation is also supported by the inferential data analysis. The ANOVA results show that farmers with more than 10 years of experience scored higher on the Climate Resilience Index (CRI) than did farmers with less than five years of experience. This suggests that experiential learning has a definite impact on providing resilient outcomes. The multivariable regression results indicated that experience, access to extension services, and application of integrated management methods were valid predictors of resilience as well. The findings show that resilience is not simply conceptual, but is established through an accumulation of knowledge, institutional assistance, and adaptive behaviour.

The results of this study correspond with the theory of socioecological resilience which sees resilience as the ability for households to withstand shocks and/or changes, adapt to stressors, and reorganise themselves without losing their core livelihoods. Therefore, years of farming experience would constitute adaptive capacity, extension services represent institutional capital, and the integration of soil and livestock management represents behaviourally adaptive mechanisms. The CRI is designed to reflect the multidimensional nature of resilience by capturing all of these components that work together when determining how resilient a household will be under different conditions.

However, the results also reveal considerable uncertainty regarding the causes of climate change, with more than half of respondents unable to identify its drivers. This limited awareness constrains the effective adoption of climate-smart practices, echoing Olabanji et al. (2021) who argue that farmers' perceptions and understanding of climate risks directly shape their adaptive responses. The findings further show that most farmers attribute productivity decline to immediate and observable factors such as poor crop or livestock performance, land size, and soil fertility degradation, while few directly link these to climate change. This aligns with Zenda (2024)**,** who note that farmers often interpret climate impacts through local production outcomes rather than abstract environmental processes.

The pronounced negative effects of climate variability on both crop and livestock production underscore the vulnerability of mixed farming systems to climatic stressors. As observed by Kruger (2025), rainfall variability, drought, and heat stress collectively reduce agricultural output and threaten rural livelihoods. In response, the reliance on increased fertilizer uses as a primary adaptive strategy highlights the short-term coping mechanisms adopted by farmers but also raises sustainability concerns due to potential soil nutrient imbalances (Pahalvi et al., 2021).

While there was no correlation between soil degradation and decrease in household income in the univariate analysis, this factor was shown to have a very strong relationship with food insecurity as demonstrated by the multivariable logistic regression results. Therefore, the production shocks will initially affect the consumption and access to food at the household level and only after a period of time can these factors be related directly to income measures. This is due to the subsistence nature of agricultural production.

Moreover, the overwhelming recognition of soil degradation's impact on food security (91%) and income (83%) demonstrates farmers' awareness of the tangible economic and nutritional implications of declining soil health. This reinforces the view of van Huyssteen and du Preez (2022) that soil degradation poses both environmental and livelihood threats in sub-Saharan Africa. Consequently, promoting sustainable land management, capacity building, and integrated soil fertility management remains crucial for improving resilience and sustaining rural livelihoods in Ndwedwe.

6. Conclusion

The study examined climate resilience among smallholder farmers in Ndwedwe, KwaZulu-Natal, to understand how they perceive, experience, and respond to climate variability and change. The findings reveal that while farmers possess rich experiential and adaptive knowledge, limited awareness and understanding of broader climate change dynamics constrain the adoption of sustainable, climate-smart agricultural practices. Productivity challenges were primarily attributed to immediate and visible factors such as declining soil fertility, limited land size, and poor crop or livestock performance rather than to long-term climatic variability. Climate variability was found to negatively affect both crop and livestock production, while the heavy reliance on chemical fertilizers raises concerns about long-term soil health and sustainability. The overwhelming recognition that soil degradation diminishes food security (91%) and household income (83%) underscores the urgency of implementing integrated soil management and adaptive farming interventions. This study contributes to the growing body of literature on rural climate resilience by providing context-specific insights into the interconnections between farmer perceptions, adaptive behavior, and institutional constraints in smallholder systems. However, the case-specific scope and cross-sectional design limit the generalizability of the findings. Future research should adopt longitudinal and mixed-method approaches to capture dynamic adaptation processes over time and to explore how targeted interventions such as capacity building, improved access to climate information, and institutional support can strengthen resilience among rural farming communities.

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