The role of neglected and underutilised crops in food and nutrition security under climate change: Insights from South Africa

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Abstract

Neglected and underutilised crop species (NUS) are increasingly discussed as options to enhance the resilience, diversity and nutritional quality of food systems under climate change. However, their productivity and nutritional contribution remain insufficiently quantified at larger scales, making it unclear to what extent they can contribute to food and nutrition outcomes. In South Africa, we compare the nutritional yield and climate response of sorghum, taro, and bambara groundnut with widely grown crops, namely maize, potato, and soybean, used here as reference crops. The analysis combines AquaCrop-simulated crop yields with nutrient composition data. Reference crops achieve higher yields and total nutritional outputs in most regions, with NUS supplying median nutritional yields of approximately 4-35% of their reference crops, depending on crop and nutrient. However, NUS match or exceed reference crops for specific nutrients in parts of eastern South Africa, with sorghum exceeding maize in iron yield and taro exceeding potato in zinc yield. Under climate change, reference crops maintain higher absolute yields across all crop pairs. Yield differences between NUS and their reference crops remain stable for sorghum-maize but increase for taro-potato and bambara-soybean, favouring reference crops. Yield differences decrease in some locations, primarily due to declines in reference crop yields under less favourable, drier conditions, bringing them closer to NUS yields. Despite stronger gains in NUS productivity relative to reference crops in some locations, and advantages for specific nutrients, these remain limited. Without crop improvement, NUS are unlikely to substitute conventional crops at scale, but can complement them by contributing to micronutrient supply and production stability when integrated in suitable agroecological zones.

1 Introduction

Climate change and resource limitations are intensifying micronutrient deficiencies in many Sub-Saharan African (SSA) countries, increasing the need for resilient food systems aligned with the nutritional needs of the population. In South Africa, dietary diversity remains low, and deficiencies in iron, zinc, and vitamin A are widespread, particularly in rural and low-income communities (Labadarios, 2007; NDoH, 2017; Shisana et al., 2013). Across many low- and middle-income countries, particularly in SSA, smallholder and subsistence farming systems play an important role in household food security and dietary quality (4).

In many parts of SSA, food production is dominated by a small number of high-yielding staple crops, such as maize (5). While these staples support food energy supply, reliance on a narrow range of crops can reduce dietary diversity, limit micronutrient intake, and diminish agrobiodiversity (6,7). Furthermore, these systems are also increasingly exposed to climatic stressors, particularly in water-scarce regions (8).

Smallholder farmers are particularly vulnerable to climate change because their livelihoods and food supply depend heavily on rainfed agriculture and limited access to inputs. They can increase their resilience to climate change by adopting mixed systems that include climate-resilient crops, ensuring a more reliable food supply when mainstream crops fail (9). Diversifying farm production can also improve household nutrition by reducing production risks from shocks like extreme weather, increasing the availability of diverse food options, and increasing stable household incomes to buy diverse food items (7).

Neglected and underutilised crop species (NUS) have been proposed as one component of more diverse production systems. Many NUS are adapted to marginal environments, require fewer inputs, and can be more resilient to climate variability and extremes (10–12). Furthermore, NUS have been shown to enhance dietary diversity and promote important macro- and micronutrients, as well as serve medicinal purposes and contribute to cultural identity (9,13,14).

Despite growing interest in NUS, their role in food systems remains poorly represented due to gaps in agronomic data, modelling and incomplete nutrient composition profiles (15). As a result, they are largely absent from agricultural policy, investment, and development agendas (16). Although several studies point to the nutritional and food security benefits of NUS, most are highly site-specific, represent only a narrow range of environmental conditions, and do not contextualise their performance relative to widely grown crops. Consequently, their productivity and nutritional contribution under diverse agroecological conditions remain insufficiently tested, leaving it unclear to what extent NUS can contribute to food and nutrition outcomes relative to conventional crops. These limitations, combined with their exclusion from modelling frameworks and climate impact assessments, continue to restrict their integration into food system planning and climate adaptation strategies.

Here, we assess the nutritional yield and climate resilience of selected NUS using South Africa as a case study, comparing their performance under a high-emissions future scenario with conventional crops across diverse environmental zones. Given widespread micronutrient deficiencies in the country and the wider region, we assess crops based on their contribution to micro- and macronutrient requirements rather than calories alone. Using the AquaCrop model (Steduto et al., 2009), we simulated rainfed yields for historical and future periods under a high CO_2 emission trajectory. The model was implemented nationally across 5,838 altitude-based zones representing wide variation in climate, soil, and hydrological properties. Model outputs were combined with regional food composition data to compare nutrient outputs of three NUS versus three widely grown reference crops and to examine how yield differences between NUS and their reference crops change under climate change. This approach allows us to identify the extent to which NUS can contribute to food and nutrition outcomes relative to widely grown crops across diverse agroecological conditions.

2 Methodology

2.1 Crops

This study compares the nutritional value (adult nutrient requirements met per hectare) and climate sensitivity (yield change relative to the historical baseline) of sorghum, taro, and bambara groundnut with those of maize, potato, and soybean. Crop pairings were selected based on functional similarity (i.e. similar roles within the food system): sorghum vs. maize (cereals), taro vs. potato (root crops), and bambara groundnut vs. soybean (legumes). Reference crops served as benchmarks to evaluate the relative performance of NUS for their nutritional yield and climate change resilience.

2.2 Crop model framework

Crop simulations were conducted using a national-scale implementation of the AquaCrop model (17), applied across 5,838 altitude-based zones covering the full extent of South Africa. These zones were derived by disaggregating each of the 1,946 quaternary catchments into three relatively homogeneous climate-soil response units for crop modelling. A quaternary catchment is the smallest operational unit for water resource management in South Africa as defined by the Department of Water and Sanitation. For each altitude zone, area-weighted averages of soil depth and soil hydraulic properties (field capacity, wilting point, saturated conductivity) were derived from a terrain unit-based database (18). The model simulated crop yields for three time periods: historical (1961-1990), near future (2015-2044), and distant future (2070-2099). Climate projections were derived from six CMIP5 general circulation models (GCMs), dynamically downscaled and bias corrected to align with observed historical conditions. All simulations were run under the Representative Concentration Pathway (RCP) 8.5 scenario to assess relative crop performance under a high-emissions future. All crops were simulated under rainfed conditions during the main summer rainfall season (September-March), which represents the primary production window for smallholder systems in South Africa. Planting dates were set as follows: sorghum and bambara groundnut (15 Oct), taro (15 Nov), maize (20 Nov), potato (15 Jan), and soybean (15 Oct). Planting dates were standardised across zones to ensure comparability. They are based on typical planting windows and expert-informed dates, but do not capture local variation in management or adaptive planting decisions. Simulations assume optimal growth conditions without nutrient limitations and no weed stress. Locally calibrated and validated crop parameter files were used for sorghum (19), taro (20), bambara groundnut (21), maize (22), and soybean (23), while AquaCrop's default parameter file was used for potato (24). To restrict the analysis to current production areas, a cropland mask was applied based on spatially disaggregated rainfed harvested area data from SPAM (25) for sorghum, taro (proxied by sweet potato as a comparable tropical root crop), and bambara groundnut (proxied by other pulses). The analysis was further restricted to zones with positive baseline yields of the NUS crops. For maize, potato, and soybean, the spatial mask of their paired NUS crops was applied to ensure comparisons were made within the same production zones. Simulated crop yields were compared against yield ranges for South Africa derived from estimates of crop production in low-input, subsistence farming systems (SPAM; IFPRI, 2020), national crop statistics reported by FAO (2026), and published field-based yield observations (Franke & Sekoboane, 2021) (S5 Fig).

2.3 Nutritional yield calculation and crop comparison

We assessed nutritional yields for dietary energy and five nutrients: protein, fibre, iron, zinc, and vitamin A. The nutrients were selected for their relevance to public health and dietary quality in South Africa based on national assessments (NDoH, 2017; Shisana et al., 2013). According to these reports, anaemia and iron deficiency are prevalent across the country, with the highest burden among young children and low-income populations. Vitamin A deficiency remains a concern, especially in infants and women, despite supplementation programmes. Zinc deficiency is also widespread in South Africa

(1). Energy, protein and fibre were included as proxies for overall dietary adequacy and quality. Low dietary diversity and insufficient intake of fruits, vegetables, and whole foods are reported across all population groups (3). The selected nutrients, therefore, reflect both macro- and micronutrient gaps affecting populations across all provinces in South Africa. Because national surveys report prevalence for these nutrient deficiencies at the provincial level, we describe nutritional yield and climate resilience results by province (see S1 Fig for provincial boundaries).

Nutrient composition values of NUS and reference crops were obtained from regional food composition tables. To reduce variability in nutrient content due to environmental factors and measurement differences, we calculated the mean value for each crop across available sources from southern Africa, including South Africa (27), Malawi (28), Lesotho (29), Zimbabwe (30), and Mozambique (31). Reported values were converted to dry-weight equivalents based on the crop's water content.

Nutritional yields were calculated for each altitude zone and climate scenario as the number of adult equivalents (ages 19-50, male and female average) whose daily recommended intake (DRI) for a given nutrient could be met from the annual yield of one hectare (S1 Table). This metric combines yield and nutrient density to quantify the nutritional production potential of each crop and the extent to which that potential could meet local nutrient needs, following methods for nutritional yield assessment (32,33).

The nutritional yield (NY) was computed as:

$$NY_{c,n} = \frac{Y_c * N_{c,n} * 10{,}000}{DRI_n * 365}$$

where:

- Y_c is the yield in t dry matter ha^{-1} yr^{-1} for crop c

- $N_{c,n}$ is the nutrient concentration per 100 g of dry matter for crop *c* and nutrient *n* (kcal, g, mg, or mcg)
- DRI_n is the daily recommended intake for nutrient *n* (in the same units as $N_{c,n}$)

To evaluate the nutritional contribution of NUS, we compared their nutritional yields to those of matched reference crops. Nutritional yield ratios (in %) were calculated to identify areas where NUS provide comparable or greater nutrient supply per hectare than reference crops.

The nutritional yield ratio was computed as:

$$Nutritional\ Yield\ Ratio_n = \frac{NY_{NUS,n}}{NY_{Reference,n}} * 100$$

where $NY_{NUS,c}$ and $NY_{Reference,c}$ is the nutritional yield for nutrient *n* (adults ha $^{-1}$) of the NUS and reference crop, respectively.

2.4 Climate impact calculation and crop comparison

To assess climate impacts, crop yields were compared across each 30-year time period: historical (1961-1990), near future (2015-2044), and distant future (2070-2099). Absolute yields (t ha^{-1}) were analysed for each crop and period, averaged across six bias-corrected GCMs under the RCP 8.5 scenario.

To compare NUS with their reference crops under climate change, NUS yield differences were calculated at the zonal level as the absolute difference in simulated yields (t ha^{-1}):

$$NUS\ Yield\ Difference = Y_{NUS} - Y_{Reference}$$

where Y_{NUS} and $Y_{Reference}$ represent simulated yields (dry t ha^{-1}) of the NUS and reference crop, respectively.

Changes in yield differences over time were used to assess whether the gap between NUS and reference crops narrows or widens under climate change. This was computed as the change in the absolute NUS yield difference between historical and future values:

$$\Delta Yield\ Difference = |NUS\ Yield\ Difference_{historical}| - |NUS\ Yield\ Difference_{future}|$$

Positive values indicate convergence, where the yield difference decreases, while negative values indicate divergence, where the yield difference increases.

To identify the drivers of these changes, yield changes over time for NUS and reference crops were compared to distinguish whether convergence or divergence results from yield increases or declines in one or both crops. In addition, NUS yield differences were compared with productivity levels of NUS and reference crops, and with key climate variables (aridity, temperature, and rainfall), to identify drivers of NUS yield differences.

3 Results

3.1 Nutritional yields of crops in South Africa

Nutritional yields of sorghum, taro, and bambara groundut as well as maize, potato, and soybean follow a strong west-to-east gradient, with the eastern half of South Africa showing the highest productivity (Fig. 1). Western and central regions have lower nutritional yields for all crops assessed due to rainfall variability.

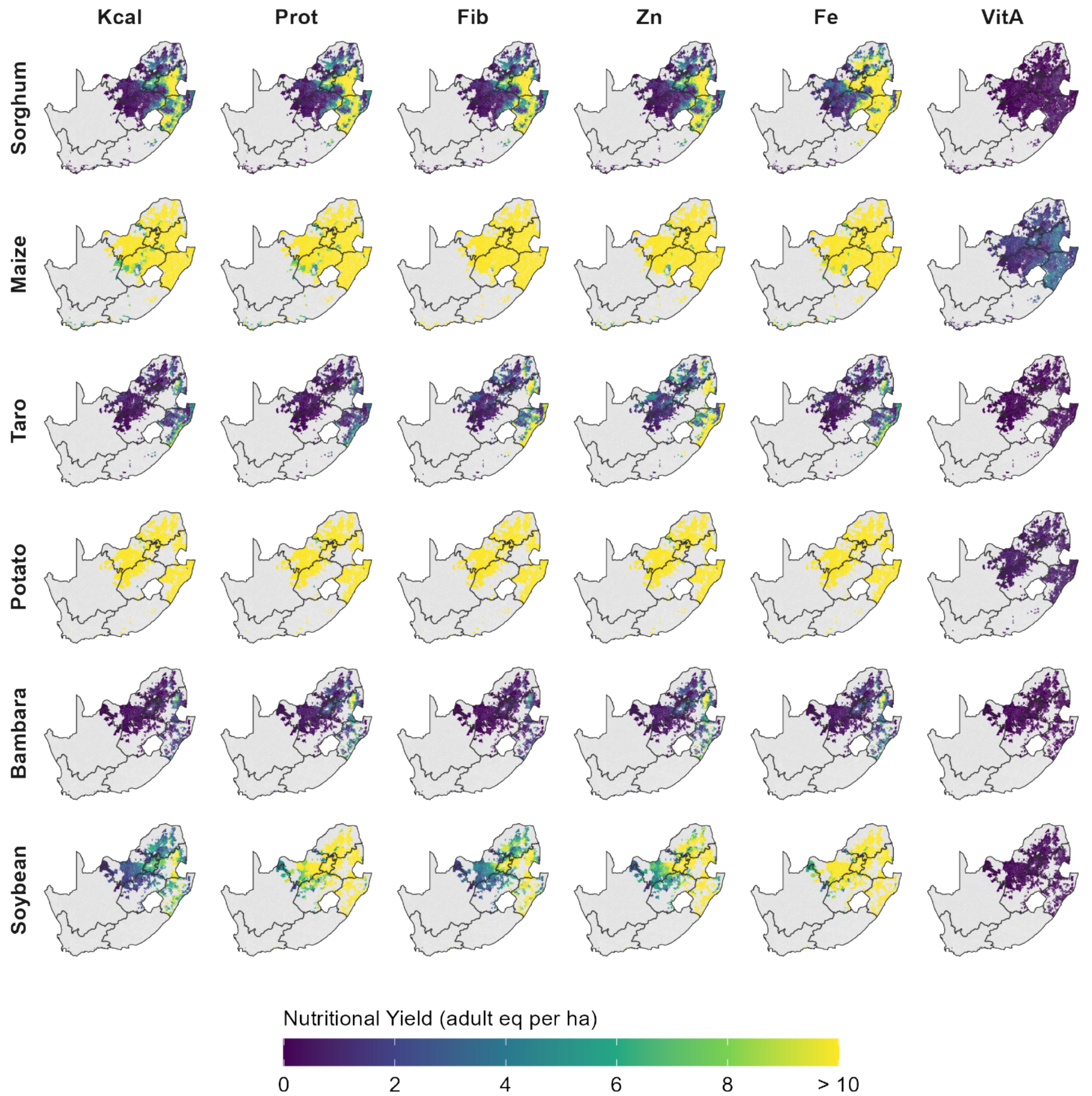


Fig 1: Spatial distribution of nutritional yields (adult equivalents ha⁻¹) for sorghum, maize, taro, potato, bambara groundnut, and soybean under baseline conditions. Maps show spatial patterns of nutritional yields (adult equivalents ha⁻¹) for energy (kcal), protein, fibre, zinc, iron, and vitamin A.

Sorghum has the highest nutritional yields primarily in the eastern and northeastern zones, notably in the provinces of Mpumalanga, KwaZulu-Natal, and Gauteng (cf. S1 Fig), particularly for iron. Taro yields for fibre and zinc are highest in Limpopo, Mpumalanga and along the eastern coastal belt in KwaZulu-Natal. Bambara groundnut yields are comparatively lower but follow a similar geographical pattern, with the highest productivity in the eastern and northeastern zones, particularly in Mpumalanga and KwaZulu-Natal. Reference crops follow similar spatial patterns, with highest nutritional yields in the eastern provinces.

3.2 Nutritional yields of NUS compared to reference crops

On average, nutritional yields of NUS are lower than those of their reference crops (Fig 2). Whilst they can be more nutrient-dense (S2 Fig), crop yields are much lower (S3 Fig and S4 Fig).

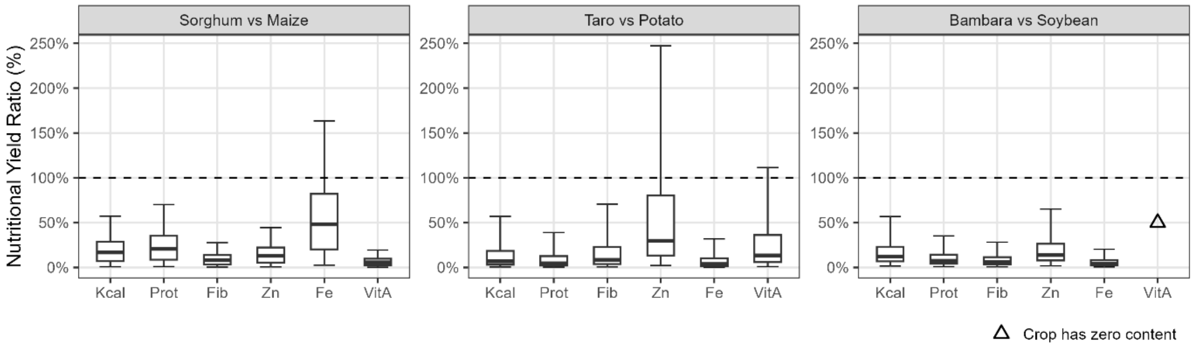


Fig 2: Nutritional yield ratios (in %) of NUS compared to reference crops under baseline conditions. Boxplots show the distribution of nutritional yield ratios for NUS compared to reference crop for energy (kcal), protein, fibre, zinc, iron, and vitamin A. Comparisons are shown for sorghum vs. maize, taro vs. potato, and bambara groundnut vs. soybean. Boxplots show interquartile range (q25-q75) with medians as horizontal lines; whiskers span the 1st-99th percentiles. Triangles indicate nutrients with zero content in the reference crop.

Sorghum generally has lower nutritional yields relative to maize across most regions (median ratios: 16.9% energy; 20.7% protein; 8.2% fibre; 13.1% zinc; 48.3% iron; 5.76% vitamin A), yet Iron yields exceed those of maize in some areas. Taro has lower nutritional yields than potato across most regions (median ratios: 6.87% energy; 4.70% protein; 8.52% fibre; 29.8% zinc; 3.84% iron; 13.4% vitamin A), but shows advantages for zinc in higher-performing regions where yields exceed potato. Vitamin A is another nutrient where taro yields match or surpass those of potato at specific locations. Bambara groundnut consistently has lower nutritional yields than soybean (median ratios: 12.2% energy; 7.54% protein; 6.07% fibre; 13.9% zinc; 4.35% iron).

Areas with high nutritional yield ratios are concentrated in the eastern provinces for all crops and nutrients (*Fig 3*). Provinces with the largest areas where NUS achieve higher nutritional yields than their reference crops include KwaZulu-Natal and Mpumalanga.

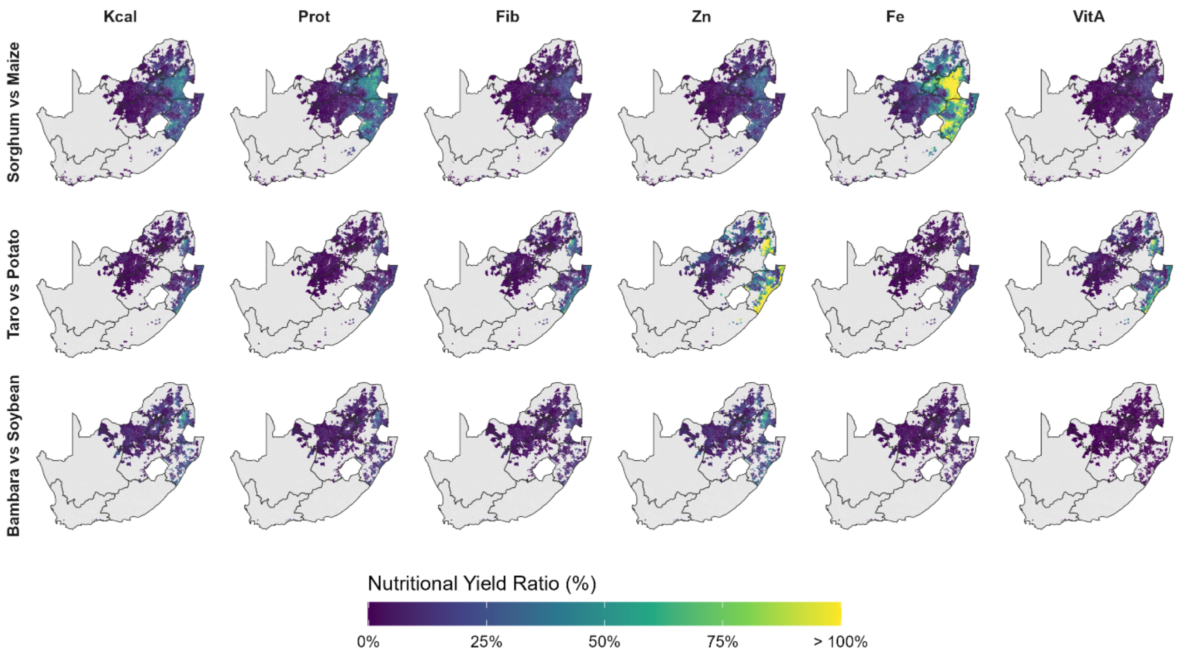


Fig 3: Spatial distribution of nutritional yield ratios for NUS compared to reference crops. Maps highlight locations where nutritional yields of sorghum, taro, and bambara groundnut approach or

exceed (yellow) those of maize, potato, and soybean, respectively. Rows represent crop pairs; columns correspond to energy (kcal), protein, fibre, zinc, iron, and vitamin A.

Sorghum achieves higher iron yields than maize in parts of Mpumalanga and KwaZulu-Natal, with smaller occurrences in other provinces. Additionally, in many areas within these provinces, sorghum yields reach at least half of maize yields. Taro achieves higher zinc yields than potato in Mpumalanga and KwaZulu-Natal, with smaller areas in Limpopo. In the same provinces, smaller areas also have higher vitamin A yields than potato, with yields in the surrounding areas reaching at least half of the reference crop's yield. Bambara groundnut also performs relatively best in Mpumalanga and KwaZulu-Natal, where zinc yields in several areas are more than half those of soybean.

3.3 Changes in yield differences between NUS and reference crops under climate change

Across most zones, simulated yields of NUS are lower than those of their reference crops (Fig 4). For sorghum compared with maize, the median yield difference remains relatively stable across time periods: −3.64 t ha^{-1} under historical conditions, −3.66 t ha^{-1} in the near future, and −3.70 t ha^{-1} in the distant future. For taro compared with potato, the difference increases over time from −3.92 t ha^{-1} under historical conditions to −4.65 t ha^{-1} in the near future and −5.34 t ha^{-1} in the distant future. For bambara groundnut compared with soybean, the yield difference is smaller but consistently negative, with median values of −0.89 t ha^{-1}, −0.95 t ha^{-1}, and −1.11 t ha^{-1} for the historical period, near future, and distant future, respectively.

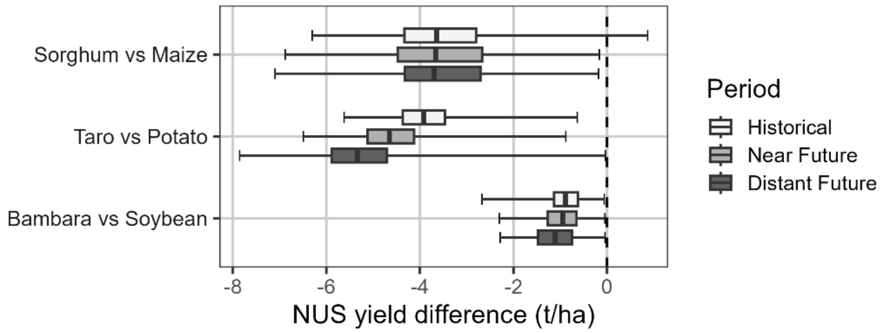


Fig 4: Distribution of NUS yield differences across crop pairs and time periods. Boxplots show the distribution of NUS yield differences (NUS minus reference crop) for sorghum vs. maize, taro vs. potato, and bambara vs. soybean for the historical period, near future and distant future. Negative values indicate lower yields for NUS than for reference crops, whereas positive values indicate higher yields.

Mechanisms underlying changes in yield differences vary across crop pairs and result in both narrowing and widening of gaps between NUS and reference crop yields (Fig 5). For sorghum relative to maize, convergence of yield differences is primarily driven by yield declines in both crops rather than improved sorghum productivity, while only a small fraction reflects sorghum gains combined with maize losses. Areas where yield differences narrow are widespread across eastern and central production regions (KwaZulu-Natal, Mpumalanga, Free State, North West, Gauteng, Limpopo), with smaller areas in the Eastern Cape (Fig 6). Divergence in yields occurs mainly in parts of the northeast, particularly Mpumalanga. Variation in maize yields contributes more strongly to changes in yield differences than variation in sorghum yields (S6 Fig). There is also a moderate association with climate, with reduced yield differences occurring under warmer and drier conditions (S7 Fig).

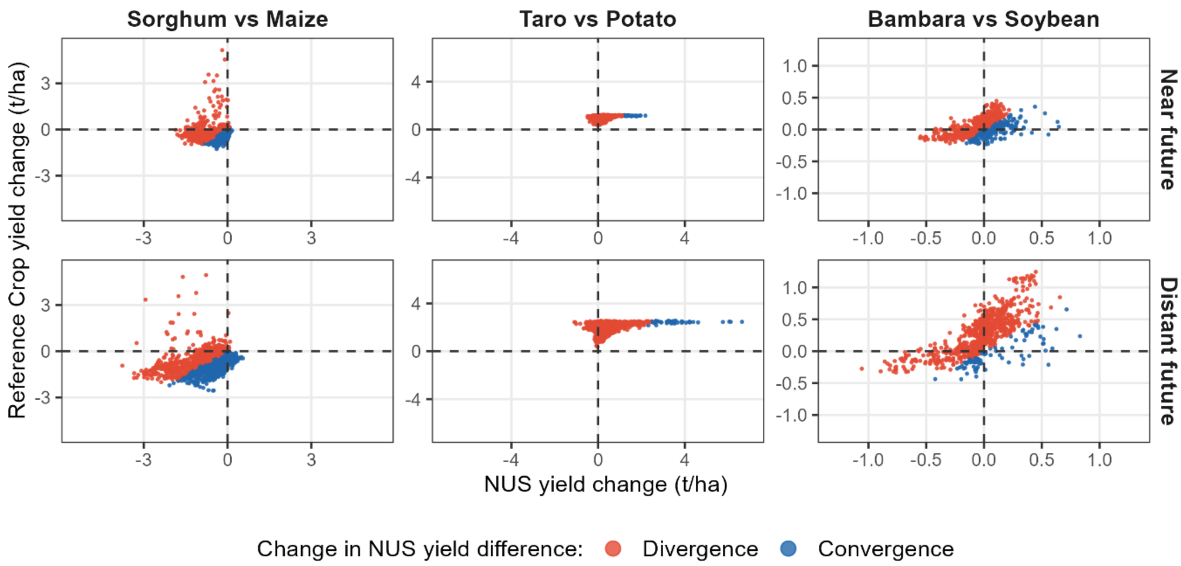
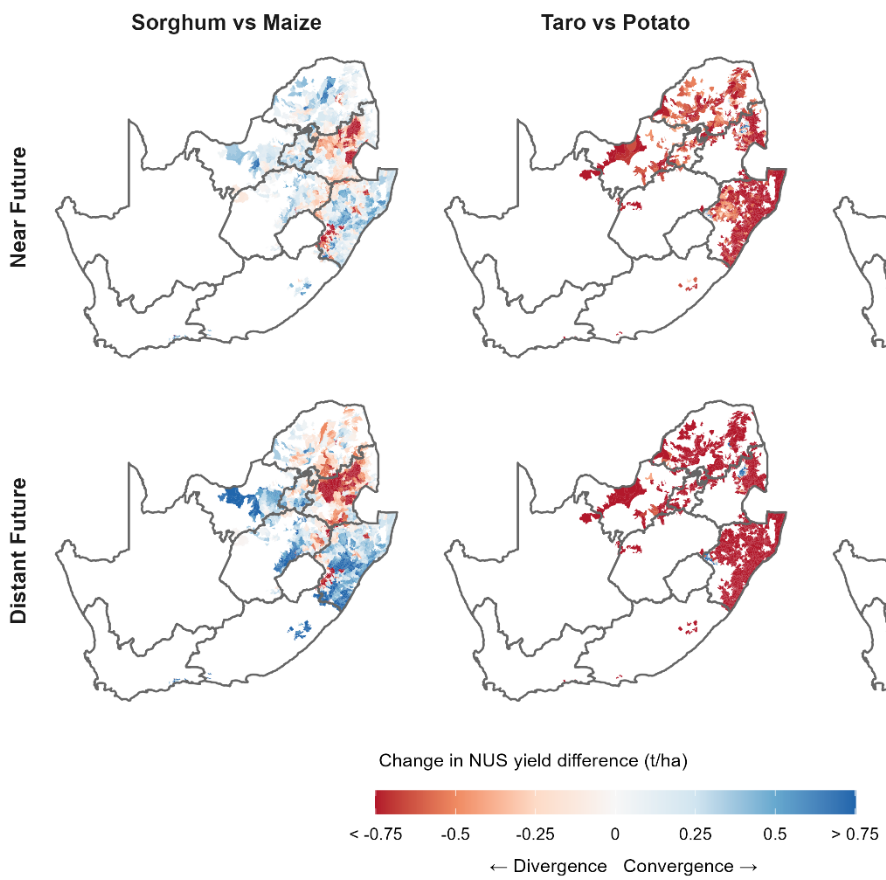


Fig 5: *Changes in NUS and reference crop yields from the historical period to the near and distant futures across crop pairs. Each point represents a simulated altitude zone, with NUS yield change on the x axis and reference crop yield change on the y axis. Colours indicate whether the difference between NUS and reference crop yields diverges or converges over time.*



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283 *Fig 6: Spatial changes in the absolute yield difference between NUS and reference crops from the*
284 *historical period to the near and distant futures across crop pairs. Maps show changes in the*
285 *absolute difference in yields (t ha^{-1}) between sorghum and maize, taro and potato, and bambara and*
286 *soybean across South Africa. Negative values indicate divergence (a widening of the yield difference),*
287 *while positive values indicate convergence (a narrowing of the difference).*

288

289 For taro relative to potato, divergence is driven by stronger increases in potato yields than taro, with
290 some cases where potato increases while taro declines. This results in increasing yield differences
291 across most production zones. Convergence in yields is limited to small areas in the eastern provinces,
292 particularly KwaZulu-Natal and Mpumalanga, where taro yields increase more strongly. Overall, yield
293 differences are smallest in zones where taro is most productive (S6 Fig). No clear relationship with
294 climatic gradients is observed for this crop pair (S7 Fig).

For bambara groundnut relative to soybean, patterns are more heterogeneous and include both convergence and divergence in yield differences. These arise through multiple mechanisms, including simultaneous yield increases, joint declines, and cases where soybean yields increase while bambara declines, and vice versa. Areas where yield differences narrow occur across several eastern and northeastern production regions, particularly KwaZulu-Natal, Mpumalanga, Gauteng and Limpopo. Areas where yield differences widen are more widespread. Changes in yield differences are mainly driven by variation in soybean yields (S6 Fig). Yield differences also show a moderate relationship with climate conditions, with smaller differences in more arid and warmer zones (S7 Fig).

4 Discussion

4.1 Nutritional contributions of NUS

Nutritional yield comparisons show that average nutrient yields of NUS are generally lower than those of conventional crops due to reduced productivity. This mainly reflects that NUS are typically cultivated using traditional, locally adapted varieties rather than improved, high-yielding cultivars, and have received substantially less breeding and agronomic development than conventional crops. Nevertheless, in some areas NUS approach or exceed nutritional yields of their reference crops. For example, taro exceeds potato in zinc yield across several zones, and sorghum can surpass maize in iron yield. Bambara groundnut, despite having substantially lower productivity than soybean, can reach half its zinc yield in some areas.

Micronutrient deficiencies remain prevalent in South Africa, particularly in iron, vitamin A, and zinc (Labadarios, 2007; NDoH, 2017; Shisana et al., 2013). These deficiencies often occur in regions where NUS show competitive nutritional yields. For instance, iron deficiency is widespread in the eastern provinces, where sorghum's iron yield exceeds that of maize.

The location and context of NUS production matter for their nutritional impact. NUS are primarily cultivated by smallholder farmers in marginalised, resource-constrained settings and are typically consumed within rural households or sold in local markets, as formal value chains remain underdeveloped (10). As such, their cultivation can contribute directly to household nutrient intake in the areas where they are grown.

There are multiple use cases and culturally relevant recipes that support the inclusion of NUS in diets. Bambara groundnut has been suggested as a protein complement in cereal-based diets (34). Sorghum is present in many African culinary traditions and has been proposed for broader dietary reintegration due to its nutritional value and cultural familiarity (14). Taro leaves are rich in vitamin A and feature in traditional dishes combined with bambara groundnut (35). Edible leaves from certain NUS, such as taro, amaranth and okra, can contribute to dietary diversity without requiring additional land or cultivation effort. This dual-use potential enhances overall system efficiency and nutritional value, especially for micronutrients (36). However, antinutritional factors in some NUS, such as high phytate concentrations that reduce iron bioavailability, need to be addressed through improved processing techniques and crop breeding (37,38).

While many studies highlight multiple potential benefits of NUS for improving nutritional outcomes, our results show that NUS remain lower yielding than conventional crops in both crop and nutritional terms across most regions, with only limited areas of nutrient-specific advantages. NUS are therefore unlikely to substitute conventional crops under current levels of breeding and agronomic development, and are better integrated into diversified farming systems, where they can complement the nutritional output of conventional crops.

Farm-level diversification, particularly where nutrient-dense crops are grown for home consumption, is associated with improved dietary quality (7). Within such systems, NUS can contribute specific nutrients, even where their overall productivity is lower. As the nutritional value of NUS varies by crop, nutrient, and region, effective integration will require aligning crop traits with local dietary needs and environmental suitability. This will require targeted support, including spatially explicit and integrated crop suitability and dietary guidelines. As climate change shifts agroecological conditions, the suitability of regions for specific NUS may also change.

4.2 Climate response and yield trends

Yield responses to climate change vary across crop pairs. Within each pair, both crops generally follow similar trends at the national level, with differences arising mainly from variation in the magnitude and spatial distribution of their responses across South Africa.

Where climate change leads to less favourable growing conditions, declines in reference crops reduce yield differences, whereas where conditions improve, both crops benefit but gains are typically larger for reference crops, leading to wider gaps. Accordingly, smaller yield differences are more common in lower-productivity or drier regions, while larger differences occur in more productive regions where reference crops respond more strongly to better growing conditions.

Although NUS remain lower yielding overall, yield differences narrow in some areas where climate change leads to relatively stronger gains in NUS productivity. This pattern occurs across all crop pairs and shows that NUS can improve their performance relative to reference crops in specific contexts. In these cases, NUS can increase their contribution to nutrient supply alongside reference crops.

An important limitation is that the simulated climate impacts reflect long-term changes in rainfall, temperature and related climate conditions. While sorghum is widely recognised for its drought tolerance (39), this characteristic is not captured in our analysis, which focuses on long term trends in mean yield rather than performance under short-term droughts and other weather extremes.

The differences in climate responses between NUS and conventional crops suggest that integrating NUS into diversified farming systems can enhance resilience. Crop diversification reduces reliance on single crops and improves income stability by increasing the likelihood that some crops remain productive when others are impacted by climate, pests, diseases or other risks. Previous studies show that households with more diverse cropping systems were better able to maintain dietary diversity during periods of stress, such as droughts (7).

NUS also present opportunities to expand production on land where environmental constraints limit more mainstream crops. Many species are well adapted to marginal conditions, offering a buffer against climate-related risks such as water scarcity and land degradation (11,12).

Our results show that nutritional yield advantages of NUS are limited to specific locations rather than widespread. This spatial heterogeneity indicates that NUS are best suited to specific agroecological niches, suggesting that promotion should prioritise suitable zones where NUS offer clear benefits rather than blanket expansion, underlining the need for nutrition and climate informed spatially explicit guidelines to support their deployment.

4.3 Policy and food system integration

Greater deployment of NUS in suitable areas can contribute to making food systems more climate-resilient and nutrition-sensitive, but this will require addressing both agronomic and market barriers. Our results show that NUS are not uniformly high-yielding or climate resilient, but their advantages are crop- and location-specific and are likely to change over time due to the changing climate. NUS are not a direct substitute for mainstream crops but should complement them to diversify production systems and reduce risks.

Given the limited breeding and agronomic development of most NUS, their productivity is likely to remain lower than that of conventional crops, under current conditions. Long-term breeding programmes could increase genetic gains in these crops, although such efforts still remain limited (40). Where NUS already show relative advantages in specific nutrients or environments, such improvements could strengthen their role within those niches. This points to the need for spatially explicit targeting of niche environments where they have a comparative advantage. Suitability maps provide a foundation for this targeting (11,12), but they should be expanded to incorporate nutrition needs so that NUS are deployed in areas where they are both well-suited for production and able to address specific nutrient gaps.

Even where NUS provide higher nutritional yields, adoption is constrained by practical and market-related factors that need to be addressed. For example, sorghum faces limited uptake despite its high iron content due to deeply entrenched consumer preferences and existing market infrastructure that favour maize (14). Bambara groundnut remains limited by long cooking times, low consumer familiarity, and minimal commercial investment (41,42).

Substitution strategies that reintroduce NUS into familiar dishes, such as replacing maize with sorghum in porridges, can support gradual dietary change. Cultural familiarity with many NUS can facilitate uptake, particularly when paired with growing consumer demand for sustainable and nutritious foods. Addressing social stigma is also important, as NUS are still perceived as “poor people’s food” or “wild crops” (43). Public procurement programmes such as school feeding schemes can play an important role in stimulating demand for NUS and countering negative perceptions. In Kenya, incorporating NUS into school meals improved dietary diversity while reducing costs (44).

NUS intersect with multiple policy domains, and their inclusion can generate broad co-benefits. Their contributions to food and nutrition security are increasingly recognised by many studies (45), and many species are associated with specific health-promoting properties (13). Beyond nutritional benefits, NUS can support a range of objectives in natural resource management as they are suited to water-scarce and resource-constrained environments (46). Thus, broader adoption of NUS would align with policy goals for climate adaptation and sustainable land use. Several NUS also hold cultural significance and play an important role in traditional diets, local identities and support heritage conservation, particularly in rural communities (14). Given their multiple uses and co-benefits, such policies will require coordinated efforts across sectors including agriculture, water, environment and health.

4.4 Limitations and uncertainty

This analysis is subject to several limitations related to both crop modelling and nutritional yield estimation. Nutrient composition data for many NUS is limited, with key nutrients less consistently represented in available food composition databases than for conventional crops. Furthermore, bioavailability and the effects of processing, which can significantly influence nutrient uptake (34), are not accounted for in the nutritional yield estimates. Improved food composition data are needed to refine future assessments.

Climate impacts were assessed using 30-year averages, which smooth over short-term variability. As a result, the resilience of certain NUS to acute events, such as droughts or heatwaves, is not captured. For instance, sorghum is often more tolerant of short dry spells than maize and is therefore planted by farmers in unusually dry years. Examining nutritional yield per unit of water rather than land may show additional benefits for water-efficient NUS, which may be overlooked in long-term averages that smooth over interannual variability. Future research should address short-term performance of NUS compared with reference crops, including responses to climatic extremes and water use efficiency.

Our crop model used uniform assumptions, such as fixed planting dates and input levels, and does not simulate adaptive practices like shifting planting windows or changes in crop management. These constraints may lead to over- or under-estimation of crop performances under future climate scenarios (47). In addition, crop model parameters were calibrated in a single growing region and then applied uniformly across all production zones in South Africa. For potato, our model used a generic parameterisation due to the lack of locally calibrated parameters.

Finally, the limited application of crop models to NUS (15) contributes to broader research gaps in understanding their productivity under different conditions, including input needs and responses to climatic stress. Compared to mainstream crops, for which a wide range of models and location-specific calibrations are already available, NUS remain underrepresented. Identifying where NUS can be most beneficial requires more refined and spatially explicit modelling approaches to generate crop suitability maps. Such tools are essential to guide policy and investment, especially under changing climatic conditions.

5 Conclusion

This study assessed the nutritional yield and climate resilience of selected NUS and mainstream reference crops in South Africa by combining crop yield projections with nutrient composition data. Our findings show that, despite generally lower average yields than their reference crops, some NUS such as taro and sorghum can match or exceed conventional crops in micronutrient yield in specific regions. Climate projections indicate that NUS remain lower yielding than reference crops across most regions. However, they can become relatively more competitive in places where major crops perform poorly, and very occasionally when NUS themselves improve significantly.

NUS are not a direct substitute for mainstream crops but can complement them in diversified systems, providing nutritional, agronomic, environmental and socio-cultural benefits. Their potential is concentrated in niche environments, making spatially explicit targeting essential. Suitability maps offer a foundation for this targeting and should be advanced to integrate nutrition needs so that NUS are deployed where they are both productive and able to address dietary gaps. Expanding the application of crop models to underutilised species, as demonstrated here, will be critical for identifying these opportunities across SSA, where nutrient deficiencies and climate adaptation needs persist.

NUS can complement major crops and improve nutrition if supported by better farming practices, breeding programmes, strong value chains, and coordinated policies. However, their benefits depend on having the right tools and support to make the most of their advantages in specific contexts.

6 Author contributions

TC: Conceptualisation, Methodology, Formal analysis, Investigation, Visualisation, Writing - original draft. RK: Methodology, Conceptualisation, Writing - review & editing. TM: Methodology, Conceptualisation, Writing - review & editing. MN: Formal analysis, Writing - review & editing. PS: Conceptualisation, Supervision, Writing - review & editing. All authors read and approved the final manuscript.

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8 Competing interests

The authors declare that they have no competing interests

9 Data availability

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request. Supporting information is provided to describe the modelling setup and additional analyses.

10 Supporting information

S1 File. Supporting information. Supplementary methods, tables, and figures describing the crop nutrient density, crop yield comparisons, spatial patterns in simulated yields, crop model evaluation, and sensitivity of results across climatic and agroecological gradients.

S1 Fig: Map of South Africa's nine provinces.

S2 Fig: Nutritional composition of NUS (sorghum, taro, bambara groundnut) and reference crops (maize, potato, soybean), based on regional Food Composition Tables from South Africa, Lesotho, Malawi, Zimbabwe, and Mozambique. Bars indicate mean nutrient content per 100 g of dry matter; error bars show reported standard deviation values where available.

S3 Fig: Simulated rainfed crop yields (dry t ha^{1}) for NUS (sorghum, taro, bambara groundnut) and their reference crops (maize, potato, soybean) across three time periods: historical period (1961-1990), near future (2015-2044), and distant future (2070-2099). Boxplots show interquartile range (q25-q75) with medians as horizontal lines; whiskers span the 5th-95th percentile. Points indicate maximum values. Values represent model means from six bias-corrected CMIP5 GCMs under the RCP 8.5 scenario.

S4 Fig: Spatial distribution of simulated rainfed crop yields (t ha^{1}) for NUS (sorghum, taro, bambara groundnut) and reference crops (maize, potato, soybean) across three time periods: historical period (1961-1990), near future (2015-2044), and distant future (2070-2099). Values represent model means from six bias-corrected CMIP5 GCMs under RCP 8.5.

S5 Fig: Comparison of simulated and reference yield ranges across NUS and reference crops. Boxplots show the distribution of AquaCrop-simulated rainfed yields across South Africa for the historical baseline period (1961–1990). These are compared with reference ranges derived from spatially disaggregated estimates of crop production in low-input, subsistence farming systems (SPAM; IFPRI, 2020) for sorghum, maize and soybean, FAO-reported yields for sub-Saharan Africa for taro and bambara groundnut (26), and published field-based yield observations for potato from smallholder production systems in South Africa (48). Whiskers indicate the 5th and 95th percentiles, boxes represent the interquartile range, and horizontal lines denote the median; for potato, the full range of observed yields reported is shown.

S6 Fig: Associations between baseline yields and NUS yield differences across crop pairs and time periods. Scatter plots show the relationship between NUS yield differences and either NUS baseline yield or reference crop baseline yield for sorghum versus maize, taro versus potato, and bambara versus soybean across the historical period, near future, and distant future. Lines show linear fits for each period, and labels report the corresponding coefficient of determination (R^2).

S7 Fig: Associations between NUS yield differences and climatic conditions across crop pairs and time periods. Scatter plots show the relationship between the NUS yield differences and aridity (calculated as evapotranspiration divided by rainfall), rainfall, and temperature for sorghum versus maize, taro versus potato, and bambara versus soybean across the historical period, near future and distant future. Lines show linear fits for each period, and labels report the corresponding coefficient of determination (R^2).

S1 Table: Daily recommended intake (DRI) values for adults used in nutritional yield calculations.

Nutrient	Unit	DRI	Source
Energy	kcal	2245	Department of Health (UK) (1991)
Protein	g	51	Institute of Medicine (U.S.) (2005)
Fibre	g	25	EFSA (2010)
Iron	mg	13	Institute of Medicine (U.S.) (2001)
Zinc	mg	9.5	Institute of Medicine (U.S.) (2001)
Vitamin A	mcg	800	Institute of Medicine (U.S.) (2001)

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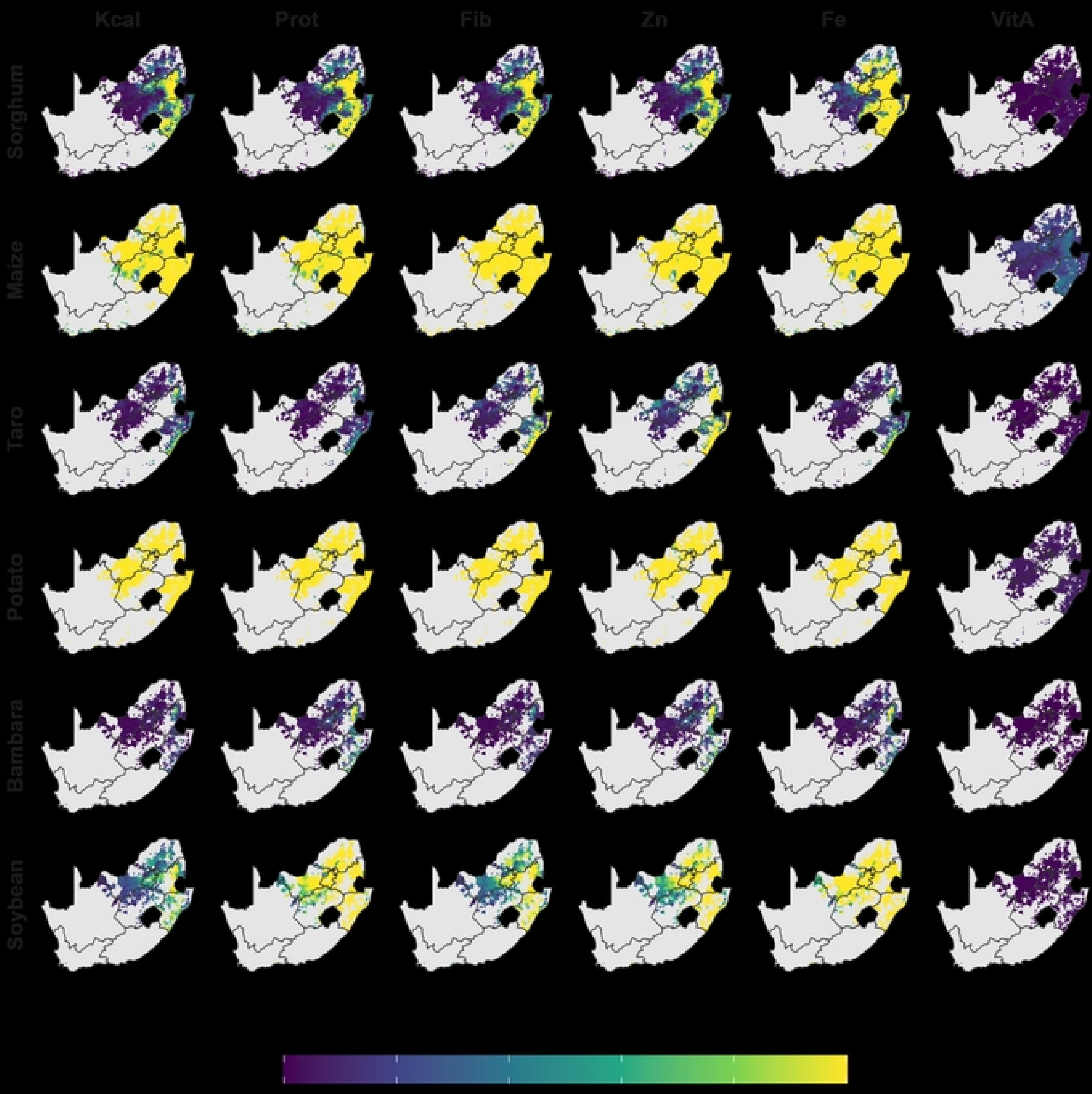
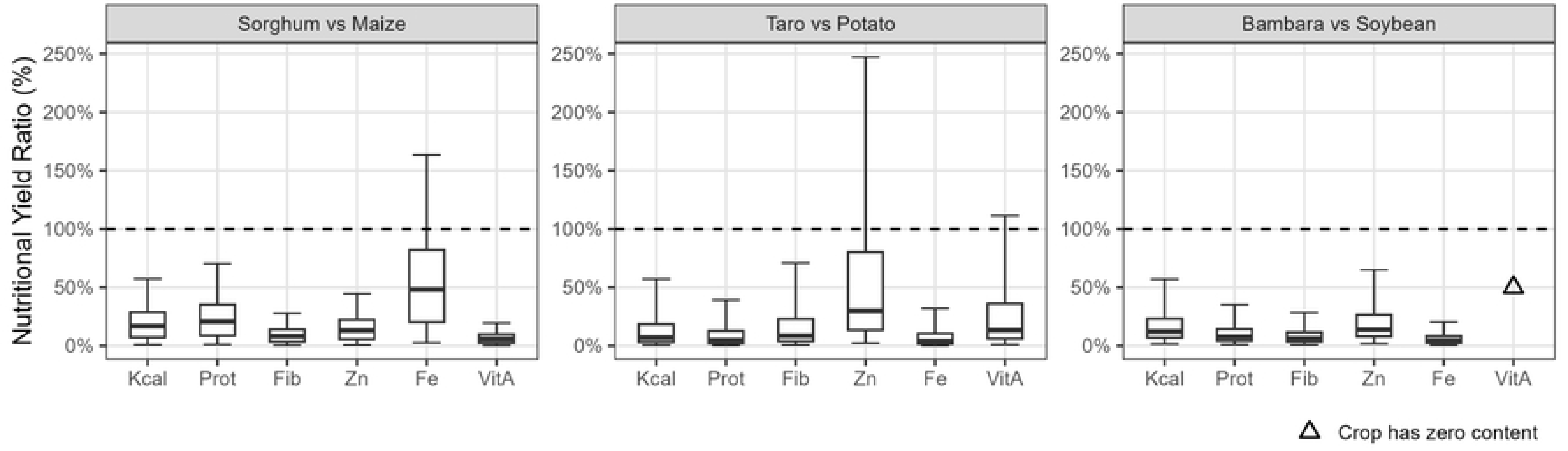
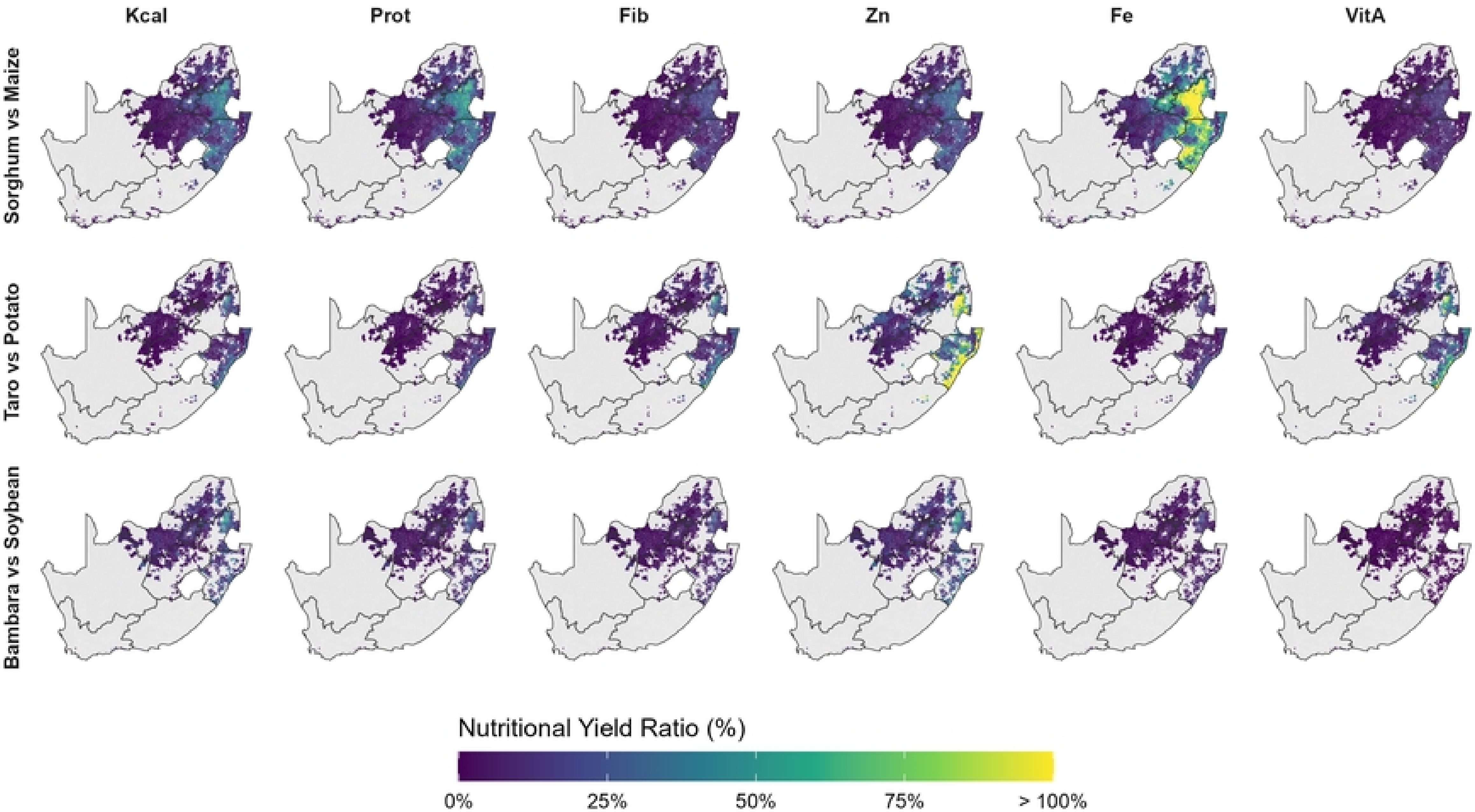
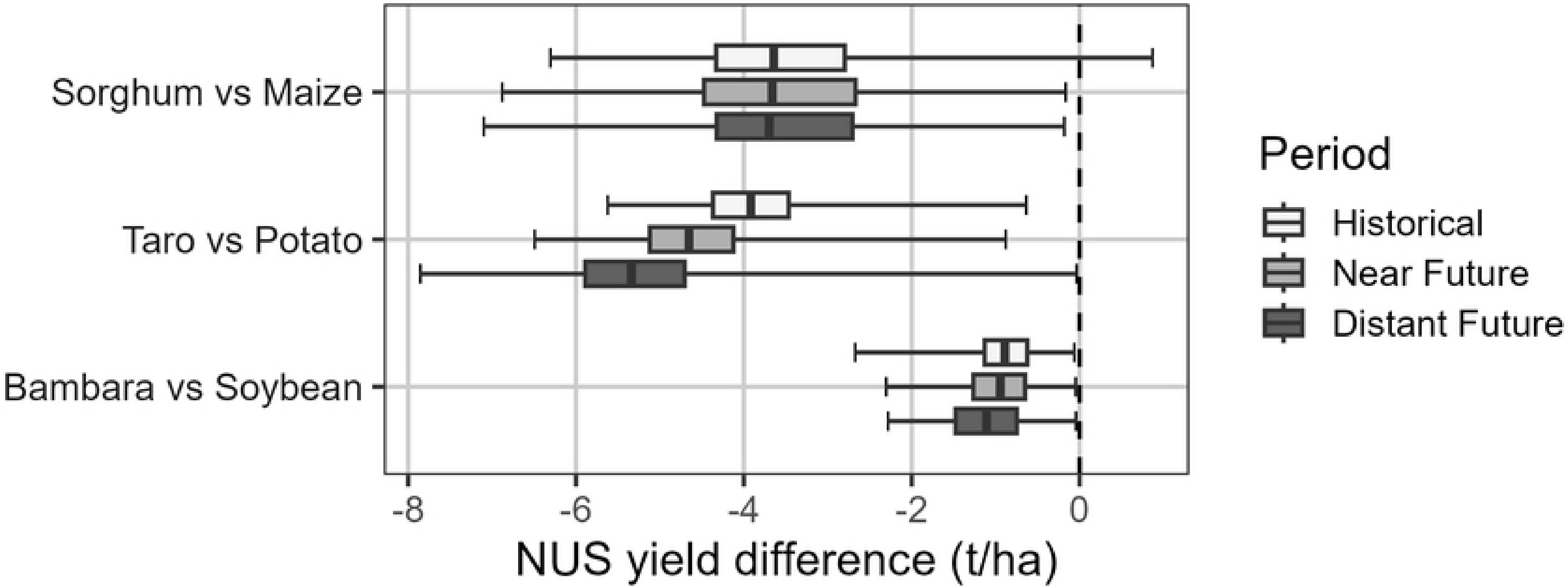

Kcal
Prot
Fib
Zn
Fe
VitA
Sorghum
Maize
Taro
Potato
Bambara
Soybean

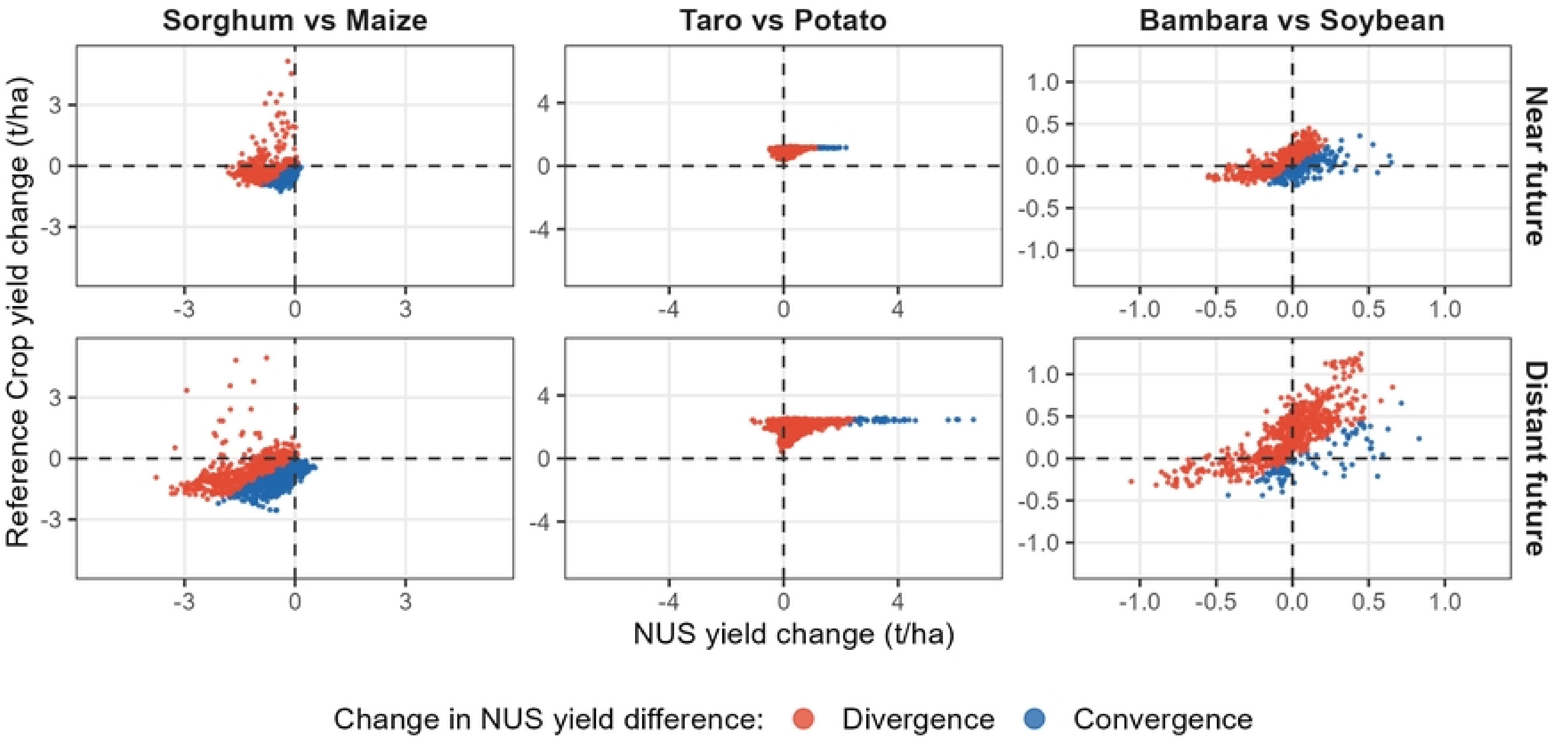

Sorghum vs Maize
Taro vs Potato
Bambara vs Soybean
Nutritional Yield Ratio (%)
250%
200%
150%
100%
50%
0%
Kcal
Prot
Fib
Zn
Fe
VitA
Crop has zero content



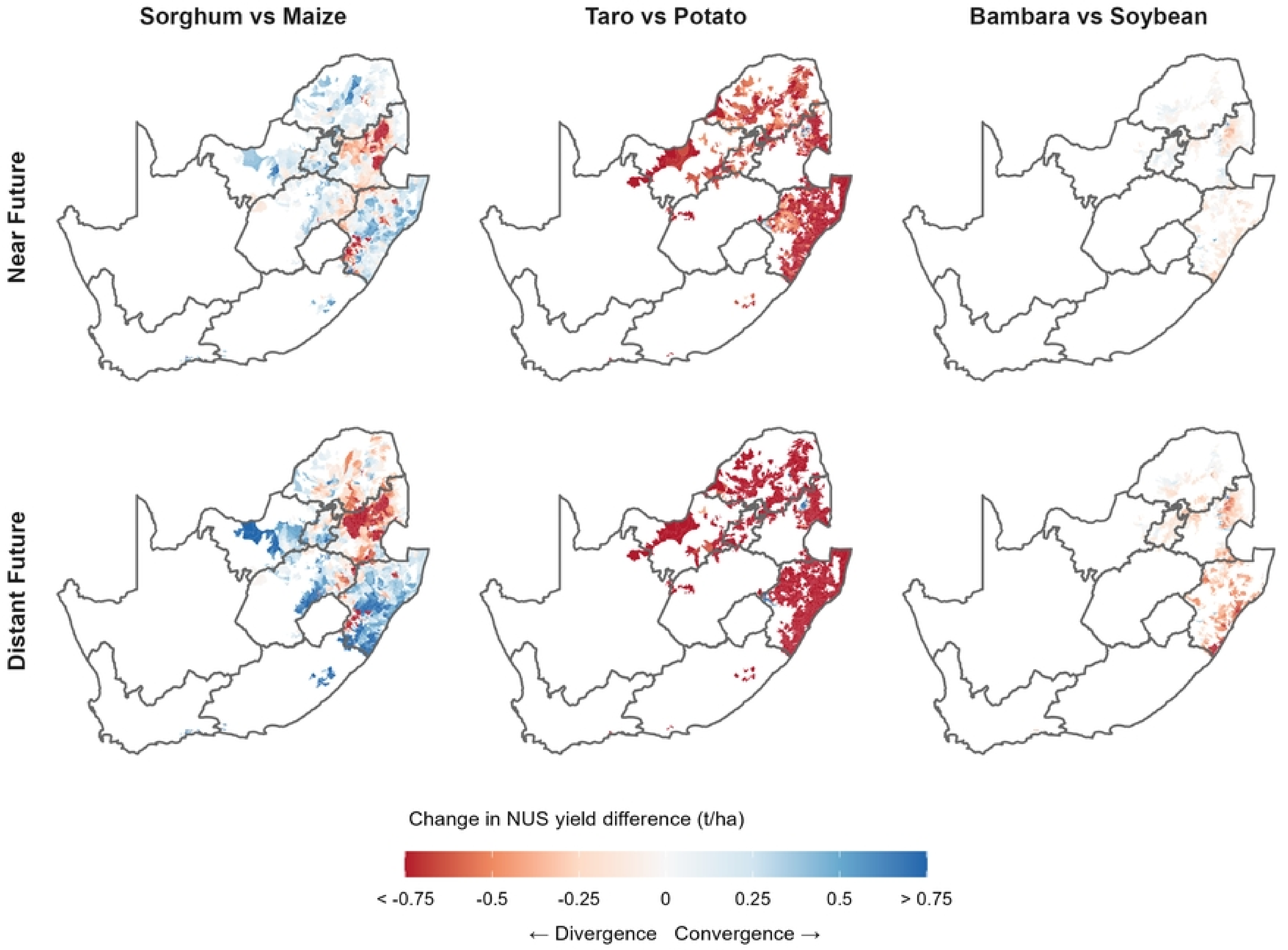
Kcal
Prot
Fib
Zn
Fe
VitA
Sorghum vs Maize
Taro vs Potato
Bambara vs Soybean
Nutritional Yield Ratio (%)
0%
25%
50%
75%
> 100%



Sorghum vs Maize
Taro vs Potato
Bambara vs Soybean
-8
-6
-4
-2
0
NUS yield difference (t/ha)
Period
Historical
Near Future
Distant Future



Sorghum vs Maize
Taro vs Potato
Bambara vs Soybean
Near future
Distant future
Reference Crop yield change (t/ha)
NUS yield change (t/ha)
Change in NUS yield difference:
Divergence
Convergence



Sorghum vs Maize
Taro vs Potato
Bambara vs Soybean
Near Future
Distant Future
Change in NUS yield difference (t/ha)
< -0.75
-0.5
-0.25
0
0.25
0.5
> 0.75
← Divergence
Convergence →