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Suboptimal maize spacing undermines yields and diminishes land utility in Malawi

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Intensifying maize production to maximize yields in sub-Saharan Africa, particularly through improved plant spacing, has been governmental policy in many locations for several decades, yet field-level adoption of government recommendations remains uneven. In Malawi, where smallholder maize farming underpins national food security, plant spacing recommendations were introduced in the 1990s to reduce persistent yield gaps. We assessed 240 farms in six agro-ecologically diverse districts in the country to evaluate adherence to the national agronomic guidelines. Field measurements revealed that less than 10% of farms had the recommended plant population of 53,333 plants per hectare, with many falling short by 25% or more. Widespread deviations were driven by excessively wide ridge and intra-row spacing, and by the practice of planting multiple seeds per station (a single sowing point within the row), which introduces intra-station competition and limits yield potential. These findings suggest that adoption of recommended plant spacing options for maize may be limited not only by constraints other than maximizing yield, e.g., labor required for ridge construction, rotation with wider-spaced crops, such as tobacco, and limited access to mechanization, but also by informational gaps regarding their benefits and feasibility. Transitioning to improved spacing through mechanization is financially feasible, even at smallholder scale, and could unlock yield increases of up to 25%. The results observed are consistent with persistent challenges across sub-Saharan Africa, where land scarcity and low-input strategies dominate smallholder agriculture. Addressing agronomic inefficiencies through labor-saving technologies and adaptive policy support is critical to advancing sustainable intensification in the region.

KEYWORDS

food security, land use efficiency, maize productivity, mechanization, plant population density, yield gap

Introduction

Maize (*Zea mays* L.) is the most important staple crop in much of Africa, including Malawi, where it plays a critical role in national food security and rural livelihoods (Erenstein et al., 2022; Minot, 2010). Nearly every subsistence farming household in sub-Saharan Africa, including Malawi, grows maize on a landholding of 0.5 hectares, or less (National Statistics Office, 2019). These households have minimal access to productivity-enhancing inputs such as improved seed, fertilizer, and irrigation. Consequently, most households harvest enough maize to meet consumption needs for only six to seven months of the year (Chirwa, 2010). Under such conditions, optimizing agronomic efficiency particularly by intensifying plant population density is essential to maximize yields and minimize land waste (Abate et al., 2015; Tollenaar and Lee, 2010).

Historically, smallholder farmers in Malawi have used a maize spacing system of 90 cm between ridges, 90 cm between stations (location where one or more seed is planted) on a ridge, and three plants per station. This configuration results in a plant population of 37,037 plants per hectare (Wiyo et al., 1999), and was designed to achieve an adequate plant density with minimal labour. However, it also results in unnecessary competition as clustered plants compete for limited water, nutrients, and sunlight, ultimately reducing individual plant performance (Ethridge et al., 2022). The wide spacing between ridges in this configuration results in open spaces, where weeds grow that intensify competition for soil resources, decrease fertilizer use efficiency, and require additional labor to maintain (Begna et al., 2001; Fahad et al., 2015).

In response to the persistent food insecurity and stagnating maize yields across Sub-Saharan Africa, the Sasakawa Global 2000 program was launched in the 1980s to promote proven agronomic technologies, including plant spacing (Borlaug and Dowswell, 1995; Denning et al., 2009; Ito et al., 2007). In Malawi, the program recommended a revised planting scheme with 75 cm ridge spacing, 25 cm intra-row spacing, and a targeted plant population of 53,333 plants per hectare (Ito et al., 2007). This scheme can boost yields by up to 25% relative to the current practice (Omara et al., 2016).

Several factors may influence maize planting configurations in smallholder systems, as maize is commonly part of a crop rotation pattern. These factors include the legacy of wider ridge spacings associated with crops such as tobacco (*Nicotiana tabacum*) cultivation (Usman et al., 2017), the use of intercropping as a risk management and land-use strategy (Beedy et al., 2010; Rusinamhodzi et al., 2012), the need to reconfigure ridges by hand for optimal cultivation of different crops, and the need to safeguard against total crop failure (Sims and Kienzle, 2016). Optimal spacing for maize intercropped with other species also depends on soil fertility, moisture availability, and intercrop compatibility (Giller et al., 2009; Mupangwa et al., 2021; Raza et al., 2019). The government recommendation, however, is uniform across the entire country and is not modified anywhere to take these agronomic variables into consideration.

The objective of this study was to quantify the gaps between farmers' actual practices and government recommendations on maize planting density in Malawi and to increase compliance with the government recommendation in order to optimize yield, limit the yield gap, and make a more efficient use of the cropped land area. We did not test a binary hypothesis that farmers "do" or "do not" follow the standard, but instead quantified the extent and patterns of non-compliance with the existing recommendations. The results further our understanding of the structural and behavioral barriers to optimal spacing and inform the design of context-responsive policies and interventions, such as mechanization support, modified ridge guidelines, or conservation agriculture systems.

Methodology

Study area, sampling design, and data collection

A stratified field survey was conducted of 240 maize fields from six agroecologically diverse districts in Malawi: Mulanje, Chiradzulu, Kasungu, Ntcheu, Mzimba, and Rumphi (Figure 1).

Within a district (Figure 1), one Extension Planning Area (EPA) was selected. Four sections were identified within each EPA, and within each section, ten contiguous maize fields were selected along a linear transect. Fields were surveyed during the rainy season when plants were generally no more than 45 cm in height. We assessed how current farmer practices compare to the national recommendation of 53,333 plants per hectare and evaluated the spatial dimensions ridge spacing, intra-row spacing, and plants per station, that drive deviations from this benchmark.

A standardized field protocol was used on all sampled farms. Along a continuous 20-m row in the field we counted the total number of ridges, the number of maize plants, and the number of planting stations (Figure 2). A planting station was operationally defined as a cluster of maize plants located within a 5-cm radius, representing a single sowing point. Measurements were replicated three times per farm.

Data analyses

We evaluated key agronomic variables—ridge spacing, intra-row spacing, number of plants per station, and overall plant population for all 240 farms. Differences across the districts were evaluated by using a one-way analysis of variance (ANOVA), with statistical significance assessed at $p < 0.05$. When significant treatment effects were observed, *post hoc* comparisons of means were performed by using Tukey's Honestly Significant Difference (HSD) test to determine pairwise differences. All analyses were performed with IBM SPSS Statistics, version 22 (IBM Corp., Armonk, NY, United States).

Results

Ridge spacing exceeded the recommended 75 cm distance in 90% of the sampled fields, indicating widespread deviation from the recommended national guidelines (Figure 3a). Statistically significant differences ($p < 0.05$) in ridge spacing were observed among districts. Specifically, ridge spacing was larger ($p < 0.05$) in Kasungu and Rumphi (91.7 and 89.7 cm) than in Mzimba and Ntcheu (79.6 and 81.2 cm).

Intra-row spacing ranged from 21 to 115 cm, with >80% of fields exceeding the recommended 25 cm (Figure 3b). Mulanje had the widest mean spacing (70.9 cm) and was significantly larger than most

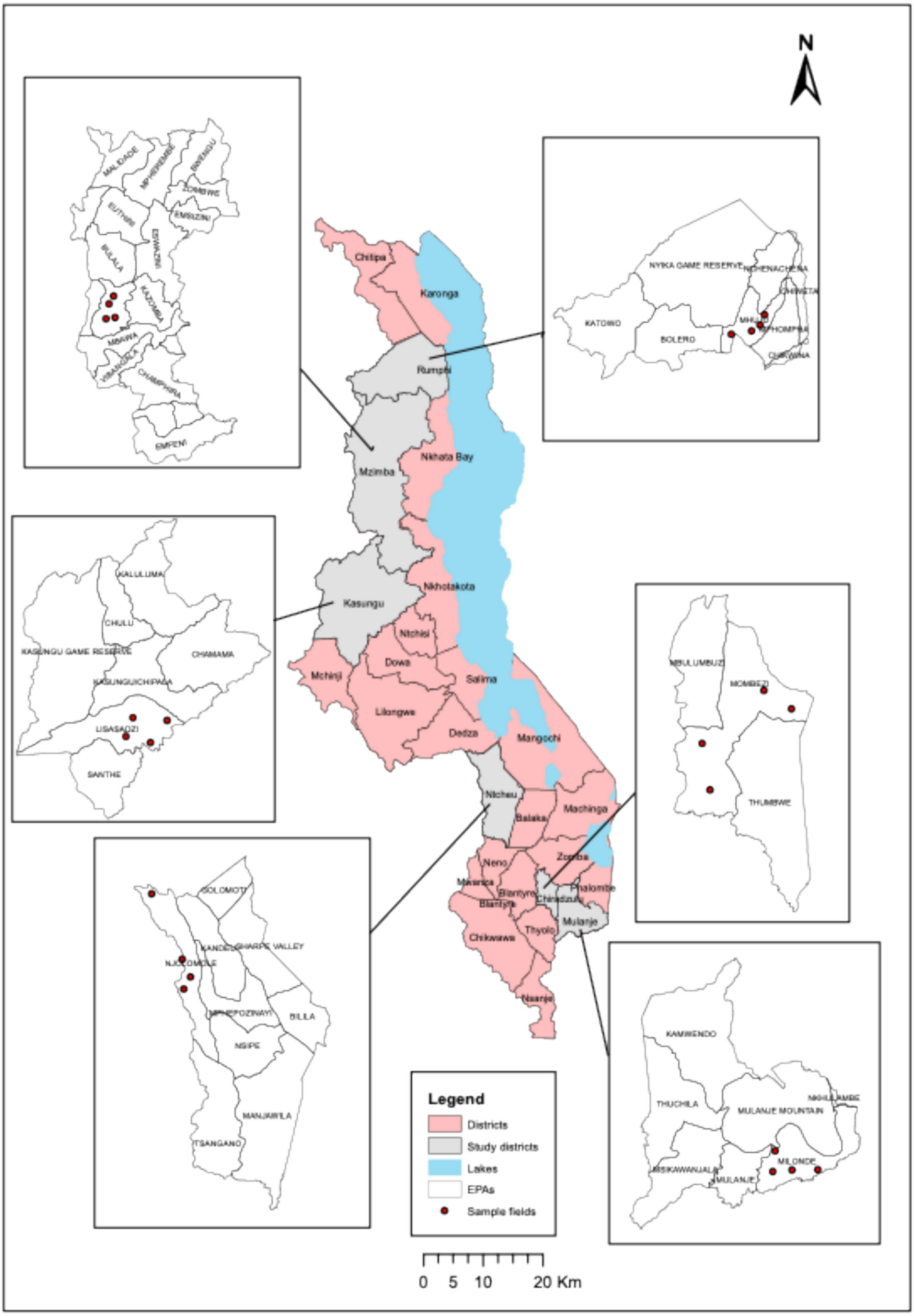

FIGURE 1
Locations of surveyed fields.

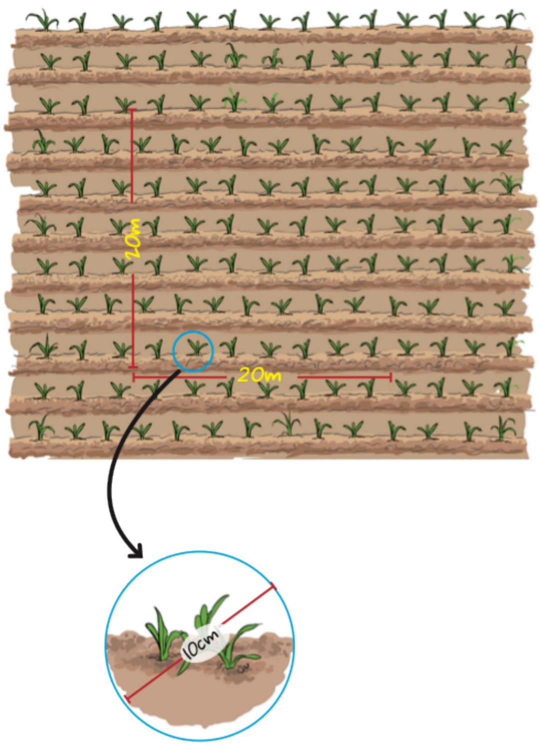

FIGURE 2
Field protocol for counting ridges, maize plants, and 5 cm planting stations along a 20 m row (each measurement was repeated three times per farm). The magnified excerpt shows a planting station, which may contain more than one plant.

districts, except Mzimba, which had an intermediate value (57.8 cm). Kasungu and Rumphi had the narrowest spacing (44.3–43.4 cm) and did not differ significantly from Chiradzulu (52.9 cm).

The number of plants per planting station varied from one to four, with most fields having two plants per station (Figure 3c). Planting density varied most in Mzimba, while in Rumphi, most fields had only one plant per station. Differences in the mean number of plants per station across the districts surveyed were not significant ($p > 0.05$).

Less than 10% of the fields reached the government-recommended plant population density of 53,333 plants per hectare (Figure 3d). Ntcheu fields had the highest mean plant population ($n = 48{,}115$), and values from Mzimba, Rumphi, and Mulanje were substantially lower ($n = 41{,}297$, 41,231, and 36,365), but the differences amongst districts were not significant ($p > 0.05$).

Discussion

Despite nearly 25 years of promoting within Malawi the recommended maize spacing of 75 cm between rows and one plant per station spaced at 25 cm within a row, adoption of these recommendations by smallholder farmers remains limited. This persistent gap suggests that the barriers to uptake may include both systemic challenges and informational gaps, such as limited awareness of the full benefits and feasibility of ridge reconfiguration. A critical constraint is the labor-intensive nature of land preparation with the traditional ridge-based system. This traditional system typically uses 90 cm by 90 cm spacing and three seeds per planting station. It results in a plant population of ~37,038 maize plants per hectare, well below the recommended 53,333. Most smallholder farmers construct ridges manually with hand hoes and follow the same furrow lines each season. Shifting from the current configuration to the recommended configuration requires a complete reconfiguration of ridge layouts, a physically demanding task that is unlikely to be feasible without mechanized support. Moreover, environmental parameters such as temperature, rainfall, and soil fertility vary greatly across Malawi and significantly influence the relationship between plant population and yield (Botoman et al., 2022; Mtewa et al., 2025; Ngongondo et al., 2011; Tadeyo et al., 2020). This variation is not consistent with a single, fixed spacing recommendation always being agronomically optimal. Nonetheless, our findings clearly indicate that the current densities are suboptimal for maize yields in most of the surveyed areas relative to agronomic potential.

Mechanizing land management

While mechanization, e.g., tractors, could enable the planting scheme transition, access to tractors is mostly on large farms and access by smallholder farmers is limited, if it occurs at all. High upfront costs, limited extension service coverage, and farmer risk aversion all hinder adoption. Many smallholders are reluctant to invest in unfamiliar technologies or practices, especially without clear, demonstrated returns (Crentsil et al., 2020). This hesitation reflects a broader dynamic amongst smallholder farmers, for whom short-term subsistence needs often are more important than long-term productivity gains, and where institutional support for beneficial transformative changes is weak.

Mechanizing the transition from 90 cm to 75 cm ridge spacing, through plowing, harrowing, and ridge construction, costs approximately MWK 121,200 ($69.77) for 0.404 hectares. According to Omara et al. (2016), this spatial adjustment alone can increase yields by 25%, raising the national average from 1.3 to approximately 1.625 tons per hectare. On a 0.404-hectare plot, this translates to an additional 0.131 tons of maize. At MWK 1,050,000 ($630) per ton, the additional maize is worth MWK 137,550 ($82.36), which exceeds the mechanization cost and allows the investment to be recovered in the first season. When combined with additional improved agronomic practices, such as fertilizer, and integrated pest and disease management, total yields could reach 3 tons per hectare (Denning et al., 2009; Toungos, 2018), or 1.212 tons on 0.404 hectares. This yield is an increase of 0.686 tons over the current yield of 1.3 tons. At current prices, the total output would be valued at MWK 720,300 ($432.46), which means an investment in mechanized ridge spacing and agronomic enhancements is profitable in the first year even at the smallholder level.

Increased land use efficiency

In addition to increased financial returns, transitioning to improved spacing also increases land use efficiency. An average household of eight requires approximately 1.168 tons of maize annually for subsistence (Mazunda and Droppelmann, 2012). At the current yield in Malawi of 1.3 tons per hectare, satisfying this demand

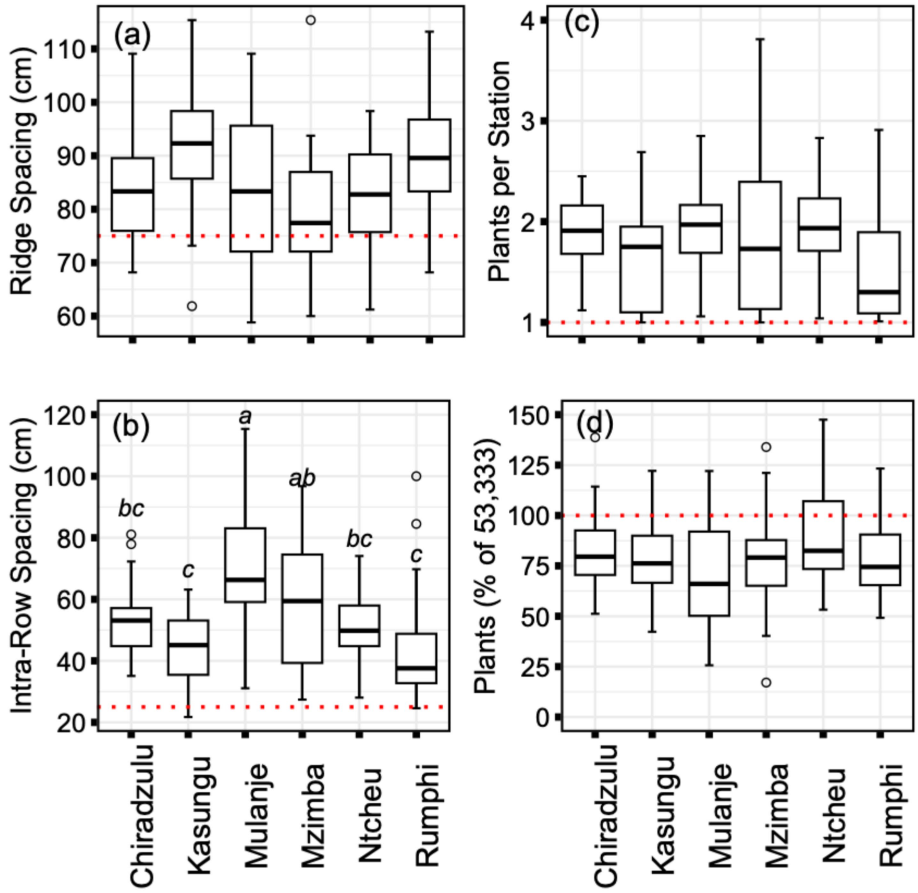

FIGURE 3
Planting configuration and population metrics across six districts. Box plots summarize four key variables relevant to maize planting: **(a)** ridge spacing, **(b)** intra-row spacing, **(c)** number of plants per station, and **(d)** plant population as a percentage of the recommended density (53,333 plants/ha). In all panels, boxes represent interquartile ranges with horizontal lines indicating medians, whiskers denote the data spread, and open circles highlight outliers. Dashed lines mark national or government recommendations: 75 cm for ridge spacing **(a)**, 25 cm for intra-row spacing **(b)**, one plant per station **(c)**, and 100% benchmark density **(d)**. Different lowercase letters signify statistically significant differences among districts ($p < 0.05$, Tukey's HSD).

would require 0.89 hectares, which is more than twice the national average landholding of 0.404 hectares (National Statistics Office, 2019). Adopting the 75 cm × 25 cm spacing with one plant per station could deliver up to 1.625 tons per hectare and reduce the land required to 0.719 hectares. Additional agronomic upgrades, e.g., improved fertilizer management, better weed control, adoption of conservation agriculture practices, use of drought-tolerant maize varieties, and soil fertility enhancements from planting legumes or incorporating organic matter, could increase the yield to up to 3 tons per hectare (Denning et al., 2009; Toungos, 2018) and require just 0.39 hectare to feed an entire family of eight. Such productivity improvements make existing village land holdings more likely to enable household food security. For farms with more land than the national average, land no longer required for maize production could be used to produce legumes, horticultural crops, or other income-generating crops, and strengthen household resilience while expanding livelihood opportunities without requiring additional land to be cultivated.

In areas where tobacco (*N. tabacum*) is cultivated as a cash crop, the 75 cm maize ridge spacing must be adapted to enable maximum tobacco production. Recommended ridge spacing for tobacco is 100 cm (Kharazmi et al., 2014), with most farmers using 90 cm spacing, and in adjacent countries some ridges may be spaced at 80 cm (Krishna et al., 2004). Thus, there appears to be flexibility in the ridge spacing for tobacco. Such flexibility may be adaptable to include ridges spaced at 75 cm, and thereby eliminate the need to reconfigure ridge layouts between seasons. Developing a zigzag or staggered intra-row planting pattern, could allow tobacco to still perform well on narrower ridges without compromising yield. The ability to use ridges spaced at 75 cm for both maize and tobacco would streamline rotational practices, reduce labor demands, and promote wider adoption of improved maize planting techniques, without undermining tobacco's role in supporting household income.

Implementation strategies

To enable conversion to 75 cm ridge spacing, the government could subsidize the one-time cost of mechanized land preparation and redefinition of row spacing. Currently, the Farm Input Subsidy Programme (FISP) provides each beneficiary household cultivating an average size farm of ~0.404 hectares with two bags of fertilizer and one pack of seed. This subsidy costs the Malawi government about

MWK 144,000 ($86.40) per household annually (National Statistics Office, 2019). The cost of fully mechanized land preparation, including plowing, harrowing, and ridge construction, is approximately MWK 300,000 per hectare, or MWK 121,200 ($69.77) for 0.404 hectares. Thus, the current government subsidy is 24% more than the amount required to prepare the land for optimal use. Unlike the annual subsidies, however, mechanization is a one-time investment with lasting structural benefits. Once ridges are realigned to the recommended 75 cm spacing, they can be maintained with an effort similar to that previously used to maintain a field with 90 cm ridge spacing in previous seasons. Thus, the tighter ridge spacing does not increase labor demand, but does increase the efficiency with which critical resources such as fertilizer (Piao et al., 2022), water (Welde and Gebremariam, 2016), and seed (Omara et al., 2016) are used, while increasing long-term yield and the return on the public subsidy investment.

Intercropping is a common strategy used by smallholder farmers to manage risk and diversify livelihoods on limited land (Snapp et al., 2002). The recommended 25 cm intra-row spacing often is incompatible with intercropping. Intercrops, e.g., legumes, require more space between maize plants to minimize competition for light and root resources, challenges that often are exacerbated in densely planted maize stands (Giller et al., 2009). Thus, intra-row spacing recommendations must be flexible depending on the intercrop grown in order to maximize the combined maize and intercrop yield, ensure agronomic compatibility, and incentivize adoption by the farmers (Beedy et al., 2010; Rusinamhodzi et al., 2012).

While mechanization can improve ridge-based systems, alternative approaches, may offer even greater potential under certain conditions. For example, flat or basin-based planting systems, particularly under conservation agriculture (CA), are a promising alternative (Nyagumbo et al., 2016). Studies from Malawi, Mozambique, and broader Eastern and Southern Africa have shown that CA practices, centered on flat planting, minimal tillage, and crop rotation, can all increase plant population density, improve soil structure, and stabilize yields over time (Mupangwa et al., 2021; Nyagumbo et al., 2016, 2020). These systems enable more precise plant spacing and reduce soil disturbance, two critical factors for optimizing yield potential. Moreover, research in South Africa indicates that high-density CA systems may yield up to 9 tons per hectare (Haarhoff and Swanepoel, 2018). However, scaling such systems requires context-specific adaptation, particularly access to appropriate mechanization, a need already identified as a national priority in Malawi's agricultural policy framework (Government of Malawi, 2016).

Study limitations

While our study provides robust empirical insight into maize planting practices across six districts in Malawi, several limitations must be considered in drawing conclusions from our results. First, intercropping was frequently observed during the survey, but its influence on spacing decisions and resulting plant population densities was not systematically assessed. Second, the study effectively maps patterns of suboptimal planting, but does not explore the behavioral, economic, and institutional drivers that may be hindering the adoption of the recommended agronomic standards. A third limitation is the lack of a direct link between observed planting densities and yield outcomes. The national spacing guidelines are premised on agronomic trials indicating optimal plant populations for yield maximization, but we did not empirically validate those assumptions under current farmer-managed conditions. Even so, our findings provide a foundation for follow-up research to quantify yield impacts and unpack adoption barriers, enabling the design of context-specific interventions to close the yield gap.

Conclusions and future perspectives

In this study we assessed the extent to which smallholder farmers in Malawi achieve the recommended maize plant population density of 53,333 plants per hectare, based on a 75 cm × 25 cm spacing guideline. Based on the field data we collected most fields fall significantly short of this benchmark and suggest that suboptimal planting density is a pervasive constraint on yield and land-use efficiency. By combining agronomic field measurements with contextual policy analysis, the ongoing yield gap found in Malawi's smallholder maize systems can be better understood. Our results challenge the assumption that information alone drives adoption and highlight how a combination of labor constraints, ridge rigidity, intercropping, and potentially limited awareness of the full benefits of reconfiguration impact adopted planting patterns.

The general failure to conform to government recommendations underscores the need for evidence-based nuanced policy interventions. Such interventions could include subsidized mechanization to overcome labor-intensive land preparation, adaptive ridge designs to enable intercropping and/or maize/tobacco crop rotation, and expanded support for conservation agriculture. Currently there is a clear mismatch between recurring input subsidies and the absence of structural investment in land preparation. Rebalancing the resources devoted to these efforts could deliver lasting improvements in productivity and resilience. Further research is needed to explore the cost-effectiveness of integrating mechanization with conservation practices across diverse agro-ecological zones and to assess the impact of other behavioral and institutional factors on smallholder decisions on planting patterns. This study provides a foundation for such inquiries and contributes to the growing body of evidence suggesting that more context-responsive, systems-based approaches to agricultural intensification are needed in sub-Saharan Africa.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

BK: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. SK: Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Investigation, Methodology. AM: Formal analysis, Writing – original draft, Writing – review & editing. FM: Writing – original draft, Writing – review & editing, Supervision. ZJ:

Writing – original draft, Writing – review & editing, Supervision. AT: Writing – original draft, Writing – review & editing. EK: Writing – original draft, Writing – review & editing. TN-N: Writing – original draft, Writing – review & editing. EC: Writing – original draft, Writing – review & editing. JK-M: Writing – original draft, Writing – review & editing. HK: Writing – original draft, Writing – review & editing. AN: Writing – original draft, Writing – review & editing. MM: Writing – original draft, Writing – review & editing. PS: Writing – original draft, Writing – review & editing. JH: Writing – original draft, Writing – review & editing, Funding acquisition, Project administration, Resources. JL: Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Funding acquisition, Project administration. LM: Writing – original draft, Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization.

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