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DECISION MAKING FOR ALEXANDERGRASS CONTROL IN MAIZE FOR PESTICIDE-FREE SMALLHOLDER CROPPING SYSTEMS

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ABSTRACT – The objective of this work was to evaluate the interference of alexandergrass (*Uroclhoa plantaginea*) on maize and to determine the economic threshold level (ETL) of this weed under different nitrogen fertilization rates in pesticide-free cropping systems. Treatments consisted of increasing nitrogen doses ranging from 0 to 345 kg ha^{-1} combined with alexandergrass densities from 0 to 328 plants m^{-2}. Shoot density, leaf area, soil cover, and aboveground dry matter of alexandergrass were evaluated as indicators of weed infestation. Considering typical ranges of maize grain yield, market prices, efficiency, and costs of manual weed control, the most reasonable nitrogen dose for pesticide-free maize production was 200 kg ha^{-1}, as it resulted in the highest ETL values when alexandergrass was present. At this nitrogen level, the ETL should be determined based on the four evaluated infestation parameters; however, on average, weed control should be performed when alexandergrass density reaches between 10 and 15 plants m^{-2}, approximately 21 days after crop emergence. This study provides guidance on the most appropriate timing for controlling alexandergrass by hoeing in pesticide-free maize production systems.

Keywords: Critical control period, integrated weed management, *Urochloa plantaginea*, *Zea mays*

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Maize is one of the most important cereals cultivated in Brazil, with the 2025/26 crop estimated at over 138,45 million tons (CONAB, 2026). Brazil is one of the world's largest corn producers, reaching 131 million tons (USDA, 2026). Grain yield and agronomic performance of maize are influenced by several factors, including weed infestation (Galon et al., 2019; Galon et al., 2022; Alptekin et al., 2023). Weeds exhibit physiological adaptations to cropping environments and management practices, particularly species that coexist closely with crops, which complicates their control (Westwood et al., 2018; Kaur et al., 2024).

Maize growth and development can be negatively affected by competition with weeds for light, water, and nutrients, resulting in reduced availability and, consequently, lower grain yield (Maqbool et al., 2016; Alptekin et al., 2023). Among the weeds affecting maize, alexandergrass (*Urochloa plantaginea*) is particularly important. This species occurs in tropical and subtropical regions worldwide and infests several crops (Migliorini et al., 2018), causing significant quantitative and qualitative yield losses.

Determining the economic threshold level (ETL) is essential for identifying the most economically viable moment to implement weed control measures, especially in pesticide-free production systems. The ETL concept states that weed control is justified only when the economic damage caused by weeds exceeds the cost of the control method (Galon et al., 2022). This approach is particularly relevant in smallholder and pesticide-free agriculture, where weed control typically relies on manual or mechanical methods that demand high labor input and increase production costs (Bari et al., 2020).

Understanding the competitive ability of weeds in economically important crops is fundamental for selecting appropriate control methods and determining optimal timing. Information on crop market value, weed control costs, and potential yield losses is critical for assessing whether weed control is economically feasible for smallholder farmers (Radosevich et al., 2007).

Nitrogen fertilization is another key factor influencing weed management decisions in maize production (Corrêa et al., 2016). Nitrogen is a costly input, and its application rate can modify weed competitiveness, while also potentially stimulating weed growth. In addition, fuel costs for mechanical weed control and labor availability are often limiting factors in smallholder systems. Therefore, weed management strategies should consider both nitrogen rates and weed infestation levels to optimize grain yield and economic returns.

Previous studies indicate that nitrogen fertilization can alter the critical period of weed interference, requiring adjustments in the timing of weed control as nitrogen rate increase (Agostinetto et al., 2017). Rizzardi et al. (2008) reported that, in the absence of nitrogen fertilization, more efficient weed management is required to maintain maize grain yield, particularly when control is delayed.

Other cropping practices must also be considered when determining the ETL, including fertilization strategies that influence both production costs and yield potential. Increased nutrient availability may allow crops to tolerate higher weed densities, thereby postponing the need for weed control interventions (Radosevich et al., 2007). Mathematical models have been widely used in weed science to estimate crop yield losses caused by weed interference (Tironi et al., 2016; Asif et al., 2017; Galon et al., 2019; Galon et al., 2022).

In pesticide-free agriculture, commonly practiced by smallholder farmers, weed control methods differ substantially from those used in conventional systems, particularly in terms of speed and efficiency (Ronchi et al., 2010). Practices such as hoeing, manual pulling, and alternative methods, including the use of fire, are generally more labor-intensive and costly than chemical weed control (Ronchi et al., 2010). Moreover, smallholder farms often lack the infrastructure, machinery, and trained personnel required for the safe and legal use of pesticides, increasing reliance on mechanical and cultural weed management practices. Consequently, optimizing the number and timing of weed control operations is essential to reduce unnecessary costs and labor demands in smallholder maize production systems.

Despite the importance of nitrogen fertilization in maize production, there is limited information on its interaction with weed emergence and the economic threshold level (ERL) of weed control in this crop. This relationship remains insufficiently understood.

Therefore, the objective of this study was to evaluate the interference of alexandergrass on maize as a function of weed density and nitrogen fertilization rate, and to determine the ETL for weed control under pesticide-free maize production systems.

Materials and Methods

The experiment was carried out at the experimental area of the Federal University of Fronteira Sul (UFFS), Erechim campus, RS, Brazil. To minimize the influence of previous vegetation, the experimental area was chemically desiccated with a non-residual herbicide (glyphosate 3.0 L ha^{-1}) 30 days before maize planting.

The maize hybrid Agroeste AS1551 was planted under a no-tillage system. Mean air temperature and daily precipitation during the experimental period are shown in Figure 1. The experimental design was a randomized complete block design arranged in a 7 x 12 factorial scheme, with experimental units measuring 3 m x 5 m. Soil fertility correction was performed based in chemical analysis, following maize fertilization recommendations (SBCS, 2016). Basal fertilization at planting consisted of 462 kg ha^{-1} of the N-P-K formulation 05-30-15. Nitrogen fertilization was applied according to the treatments at two maize growth stages: V4 and V8.

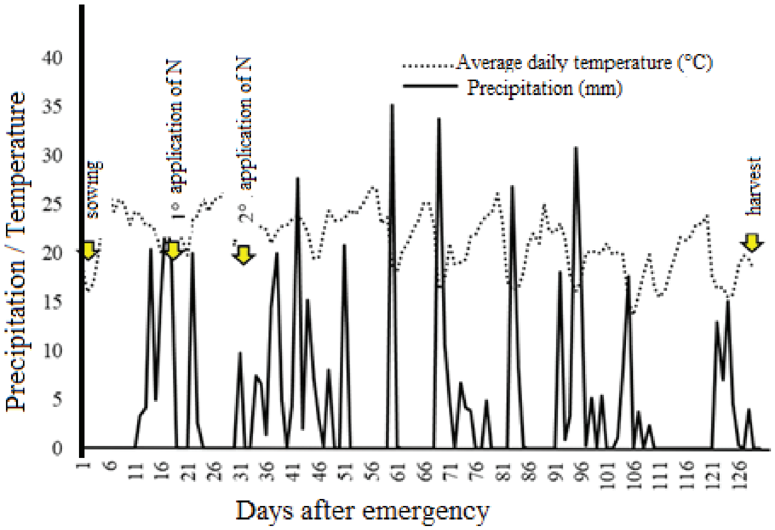


Figure 1. Average temperature and daily precipitation during the experimental period.

The treatments consisted of seven nitrogen doses (0, 57.6, 115.2, 172.8, 230.4, 288.0, and 345.6 kg ha^{-1}) combined with 12 alexandergrass densities (ranging from 0 to 328 plants m^{-2}). Nitrogen rates were defined as proportions of the technical recommendation for maize fertilization (SBCS, 2016), corresponding to 0x, 0.5x, 1x, 1.5x, 2x, 2.5x, and 3.0x the recommended dose of 115.2 kg ha^{-1}.

Alexandergrass density was established on the soil seed bank. Plants designated to remain in each plot were marked with colored tape, and excess plants were manually removed when maize was at V3-V4 growth stage (approximately 21 days after emergence, DAE) and weeds were at the two to three-leaf stage. Additional thinning was performed weekly for the following four weeks to maintain the target weed densities. Alexandergrass was allowed to coexist with maize until harvest, and all other weed species were manually removed from the plots.

Alexandergrass plant density (PD; plants m^{-2}), leaf area (LA; m^2 leaf m^{-2} soil), soil cover (SC; %), and aboveground dry matter (DM; g m^{-2}) were quantified 45 days after maize planting. Plant density was determined by counting plants within four 0.25 m^{-2} (0.5 m x 0.5 m) sampling quadrats per plot. Soil cover was visually estimated independently by two evaluators using a percentage scale, where 0 represented no soil cover and 100 represented complete soil cover. Leaf area was measured using a portable leaf area meter (CI-203, BioScience Inc.) on plants collected from the central 0.25 m^{-2} area of each experimental unit. Subsequently, plants were placed in kraft paper bags and dried in a forced-air oven at 65 ± 3 ºC for 72 h until constant weight was achieved to determine aboveground dry matter.

Maize grain yield was determined by harvesting ears from a usable area of 3.0 m^{-2} per plot when grain moisture content was approximately 13%.

Based on grain yield data, percentage yield losses relative to weed-free plots were calculated using Equation 1:

$$Yl = \left(\frac{Ya - Yb}{Ya}\right) * 100$$

Equation 1

Where:

Yl = grain yield losses (%);

Ya = grain yield without alexandergrass interference.

Yb = grain yield with alexandergrass interference.

The economic threshold level (ETL) was calculated using an equation adapted from Lindquist and Kropff (1996) (Equation 2):

$$ETL = \frac{Cc}{Y * P * \left(\frac{i}{100}\right) * \left(\frac{Ef}{100}\right)}$$

Equation 2

Where:

ETL = economic threshold level (alexandergrass plants m^{-2});

Cc= weed control cost (manual hoeing, US\$ ha^{-1});

Y = maize grain yield (kg ha^{-1});

P = maize price (US\$ per 60 kg bag);

i = percentage grain yield loss per unit increase in weed density as density approaches zero;

Ef = weed control efficiency (%).

For the variables Cc, Y, P, and Ef, three representative values from the previous 10 years were considered. Weed control cost (Cc) was estimated based on manual hoeing, considering local labor costs and operational productivity for annual crops. The average control cost was set at US\$ 50 ha^{-1}, derived from as estimated requirement of 8-man-days ha^{-1} and a daily wage converted to U.S. dollars using the average BRL/USD exchange rate of 2018 (US\$ 1 = BRL 3.87). Minimum and maximum control costs were estimated by subtracting or adding 25% to this average value, respectively.

Maize grain yield (Y) was based on the minimum, average, and maximum price paid per 60 kg bag in Brazil over the same period. Weed control efficiency (Ef) was assumed to be 80, 90, and 100%, with 80% considered the minimum acceptable efficiency for affective control.

Model fitting was evaluated using the F-test ($p \leq 0.05$). Model selection criteria included the highest coefficient of determination (R^2) and the lowest residual mean square (RMS). After testing different mathematical models, a second-degree multiple regression model was selected and applied to all variables (Equation 3):

$$z = a + bx + cy + dx^2 + exy + fy^2$$

Equation 3

Where:

z= response variable [grain yield loss (%) or ETL (plants m^{-2})];

x= nitrogen rate (kg ha^{-1});

y= experimentally measured variables (PD, LA, SC, DM) or economic and crop parameters (grain yield level, bag prices, hoeing efficiency, and control cost).

Results were presented as three-dimensional response surface plots (x, y, z), generated in the R statistical environment using the *plot3D* package.

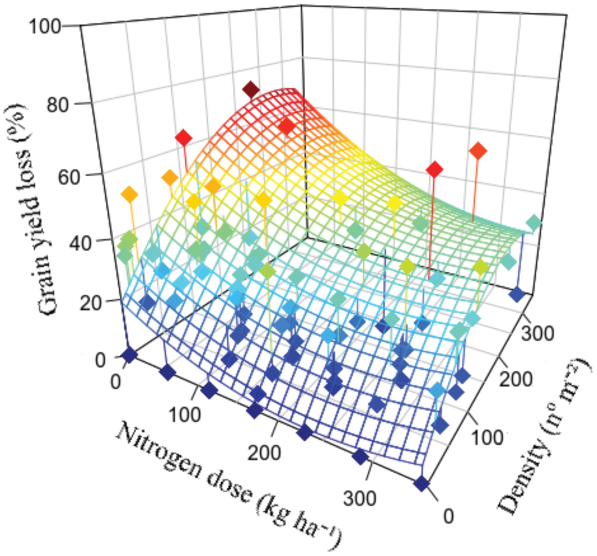
Results and Discussion

Figures 2 to 5 illustrate the interaction between nitrogen (N) rates and alexandergrass density and their effects on maize grain yield losses at harvest. Nitrogen was confirmed as a key limiting nutrient for both maize grain yield and crop competitiveness. Under field conditions where maize and weeds competed for N (Figures 2-5), reduced N availability intensified yield losses. As alexandergrass density (PD), soil cover (SC), leaf area (LA), or weed dry matter (DM) increased, maize yield losses also increased. However, consistent with the findings of Galon et al. (2015), nitrogen fertilization partially mitigated the negative effects on alexandergrass interference, indicating that competition for mineral nutrients plays a central role in this interaction. Recent studies reinforce this, showing that N fertilization enhances maize root growth, nutrient uptake, and tolerance to interspecific competition (Shao et al., 2024).

Alexandergrass density (Figure 2) caused more severe yield losses under low nitrogen availability. Yield losses exceeded 70% when maize was grown without nitrogen fertilization in association with 160 plants m^{-2} of alexandergrass. In contrast, when 230 kg ha^{-1} of nitrogen was applied at the same weed density, grain yield losses were reduced to approximately 40%. Similar results were reported by Tanveer et al. (2017), who attributed reductions in crop productivity primarily to nutrient competition between crops and weeds. This aligns with recent studies showing that higher N availability favors asymmetric crop-weed competition in cereals, reducing yield losses due to nutrient competition (Arduini et al., 2026).

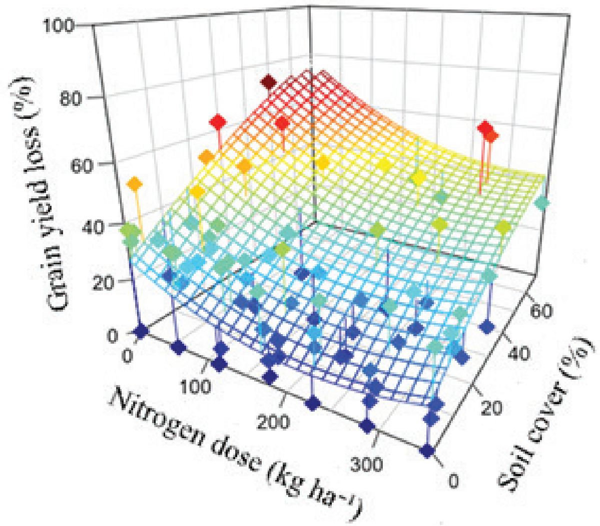
Grain yield losses associated with soil cover by alexandergrass (Figure 3) also varied according to nitrogen rate. Increased weed cover caused greater yield losses under lower nitrogen fertilization. Müller et al. (2016) reported that increasing nitrogen availability improved maize grain yield, a trend also observed by Benteo et al. (2016) in pasture systems. In the present study, plots receiving 345 kg ha^{-1} of nitrogen and exhibiting 28% soil cover by alexandergrass showed yield losses of approximately 30%, whereas plots fertilized with 100 kg ha^{-1} experienced losses close to 50% under the same level of weed cover. These results suggest that higher nitrogen inputs can enhance maize competitiveness against alexandergrass, as confirmed by recent field trials showing N rates above 200 kg ha^{-1} increased maize yield under weed pressure (Soares et al., 2020).

Similar response patterns were observed for weed leaf area (Figure 4) and dry mater (Figure 5). Maqbool et al. (2016) emphasized the importance of nitrogen fertilization for sustaining crop productivity. In the present study, when 100 kg ha^{-1} of nitrogen was applied and



$$z = 18.9 - 0.15x + 0.363y - 0.001y^2 \quad R^2 = 51.54\%$$

Figure 2. Grain yield loss (%) of Agroeste AS1551 maize hybrid as a function of nitrogen dose (kg ha^{-1}) and alexandergrass density (plants m^{-2}) 45 days after emergence. **X** = nitrogen dose; **Y =** alexandergrass density; **Z** = crop grain yield loss



$$z = 26.8 - 0.153x + 0.962y - 0.001xy - 0.003y^2 \quad R^2 = 47.83\%$$

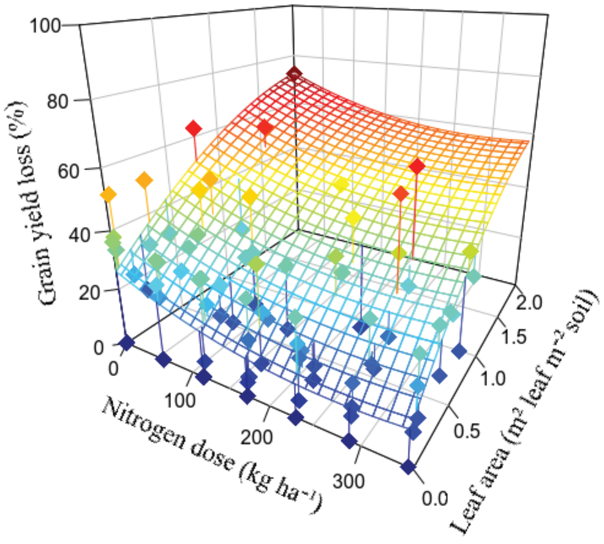
Figure 3. Grain yield loss (%) of Agroeste AS1551 maize hybrid as a function of nitrogen dose (kg ha^{-1}) and soil cover (%) by alexandergrass plants 45 days after emergence. **X** = nitrogen dose; **Y** = alexandergrass soil cover; **Z** = crop grain yield loss

alexandergrass leaf area reached approximately 1.0 m^2 leaf m^{-2} soil, maize yield losses was close to 40%. However, when 345.6 kg ha^{-1} of nitrogen was applied at the same weed leaf area, yield losses decreased to around 25%. Corrêa et al. (2016) also reported that higher nitrogen rates may provide a partial buffering effect against unfavorable environmental factors affecting crop growth. Recent studies on soybean confirm that increasing alexandergrass density causes substantial yield losses (up to 50%), supporting predictions that optimal N rates (150-250 kg ha^{-1}) can minimize penalties from C4 weeds like alexandergrass by enhancing crop competitiveness (Soares et al., 2020).

Asif et al. (2017) observed increased yield losses in forage sorghum as weed biomass increased. Similarly, in the present study, the accumulation of approximately 35 g m^{-2} of alexandergrass dry matter (Figure 5) combined with 57.6 kg ha^{-1} of nitrogen resulted in yield losses of about 40 %. In contrast, when 345.6 kg ha^{-1} of nitrogen was applied with similar weed biomass, yield losses were slightly above 20%. These findings highlight the importance of optimized maize management in reducing productivity losses caused by weed interference, particularly by alexandergrass. Nevertheless, these results do not indicate that inadequate weed control can be fully compensated for increase nitrogen fertilization, as this compensatory effect was only partial and limited to low infestation levels.

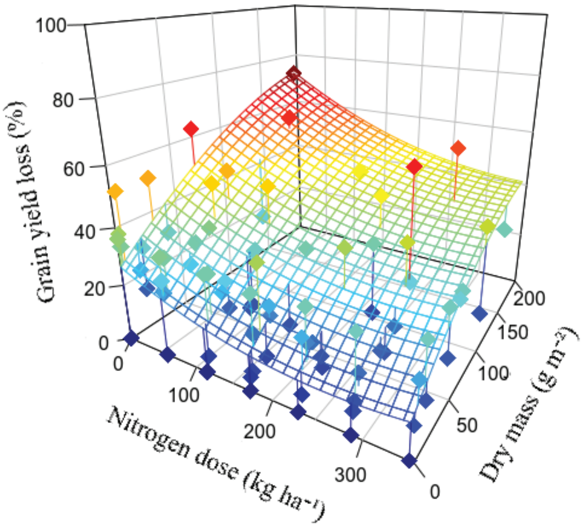
Regarding the economic threshold level (ETL), which represents the most appropriate timing for non-chemical weed control, a consistent pattern was observed across Figures 6 to 9, despite variations in grain yield estimates, maize bag prices, hoeing efficiency, and control costs. Nitrogen rates between 115 and 230 kg ha^{-1} resulted in higher ETL values, indicating that weed control could be delayed until higher infestation levels compared to the other nitrogen doses. This delay is agronomically relevant because early hoeing may require additional operations later in the season to prevent yield loss. In pesticide-free smallholder systems, maintaining productivity while minimizing the number of weed control operations is essential to reduce production costs (Vidal et al., 2005; Bari et al., 2020). Recent studies on integrated weed management in tropical maize confirm that moderate N fertilization (120-220 kg ha^{-1}) increases ETLs by 50-100%, optimizing labor and control costs in N-limited systems (Das et al., 2021).

When nitrogen was not applied (Figures 6-9), weed control was economically justified at densities below 2 alexandergrass plants m^{-2}. Tironi et al. (2016), studying sugarcane cultivars, reported even lower ETL values (0.66-0.33 plants m^{-2}) for *Urochloa brizantha.* In contrast, under optimal nitrogen fertilization rates (115-230 kg ha^{-1}), the ETL increased to approximately 11 alexandergrass plants m^{-2}, corresponding to maize yields of about 3785 kg ha^{-1} (Figure 6). Similar ETL values were observed when control



$z = 26.2 - 0.113x + 38.6y - 0.001xy - 7.7y^2 \quad R^2 = 44.77\%$

Figure 4. Grain yield loss (%) of Agroeste AS1551 maize hybrid as a function of nitrogen dose (kg ha^{-1}) and Alexandergrass leaf area (m^2 m^{-2}) 45 days after emergence. **X** = nitrogen dose; **Y** = alexandergrass leaf area; **Z** = crop grain yield loss



$z = 26.4 - 0.122x + 0.38y - 0.001y^2 \quad R^2 = 46.58\%$

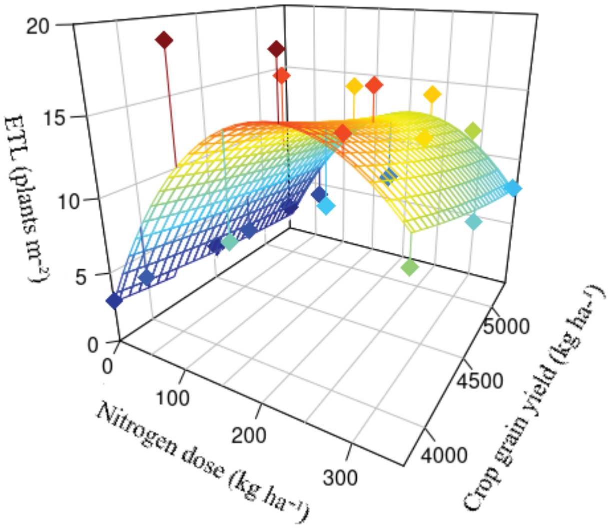
Figure 5. Grain yield loss (%) of Agroeste AS1551 maize hybrid as a function of nitrogen dose (kg ha^{-1}) and alexandergrass dry matter (g m^{-2}) 45 days after emergence. **X** = nitrogen dose; **Y** = alexandergrass dry matter; **Z** = crop grain yield loss

costs were considered (Figure 9). Galon et al. (2019) reported an ETL of 5.49 alexandergrass plants m^{-2} for six maize hybrids grown in small-scale, family-manage systems.

At higher maize yield levels (5291 kg ha^{-1}) combined with nitrogen fertilization between 115 and 230 kg ha^{-1}, the ETL decreased to approximately 7 plants m^{-2} due to the greater economic impact of yield losses (Figure 6). A comparable trend was observed under lower hoeing efficiencies (Figure 8), where the ETL was approximately 10 plants m^{-2}.

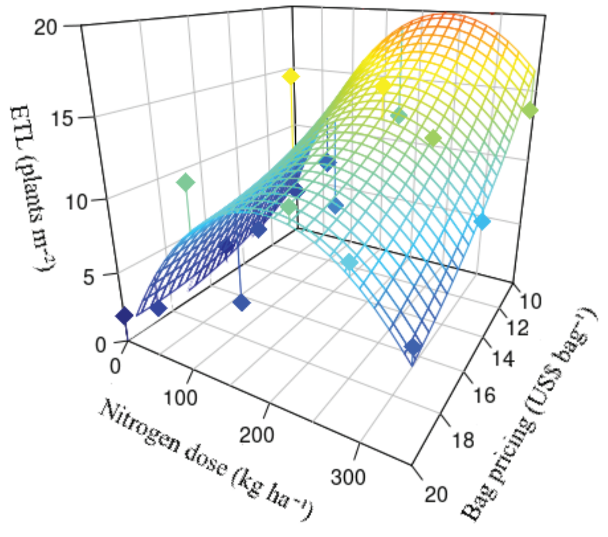
Under higher nitrogen fertilization (288 kg ha^{-1}), similar ETL values were observed when maize prices were low (Figure 7). Overall, a nitrogen fertilization range between 115 and 230 kg ha^{-1} appears to be optimal, as it allows weed control to be postponed to higher infestation levels compared to lower nitrogen inputs.

However, nitrogen recommendations must consider fertilizer costs. High nitrogen rates (288-345 kg ha^{-1}) may not be economically viable in some scenarios. These decisions should be made on a case-by-case basis, as nitrogen price variability was not addressed in this study.



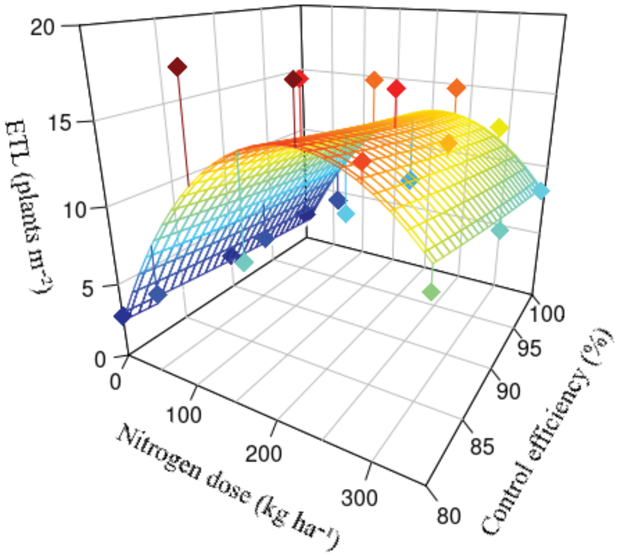
$z = 18.2 + 0.139x - 0.006y \quad R^2 = 63.5\%$

Figure 6. Economic threshold level (ETL) of alexandergrass (plants m^{-2}) in maize as a function of grain yield (kg ha^{-1}) and nitrogen dose (kg ha^{-1}). **X** = nitrogen dose; **Y** = crop grain yield; **Z** = ETL



$z = 19.3 + 0.148x - 1.97y - 0.002xy + 0.051y^2$ $R^2 = 68.3\%$

Figure 7. Economic threshold level (ETL) of alexandergrass (plants m^{-2}) in maize as a function of 60 kg grain bag price (US\$ bag^{-1}) and nitrogen dose (kg ha^{-1}). **X** = nitrogen dose; **Y** = maize bag price; **Z** = ETL



$z = 18.1 + 0.137x - 0.296y + 0.001y^2$ $R^2 = 62.43\%$

Figure 8. Economic threshold level (ETL) of alexandergrass (plants m^{-2}) in maize as a function of hoeing efficiency in alexandergrass removal (%) and nitrogen dose (kg ha^{-1}). **X** = nitrogen dose; **Y** = alexandergrass control efficiency; **Z** = ETL

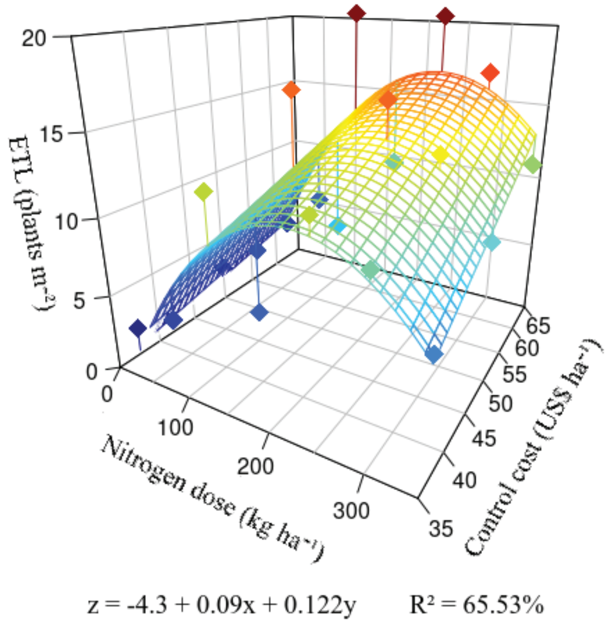


Figure 9. Economic threshold level (ETL) of alexandergrass (plants m^{-2}) in maize as a function of alexandergrass hoeing cost (US\$ ha^{-1}) and nitrogen dose (kg ha^{-1}). **X** = nitrogen dose; **Y** = alexandergrass control cost; **Z** = ETL

Conclusions

Considering typical ranges of maize grain yield, market prices, and the efficiency and cost of manual weed control, an application rate of approximately 200 kg ha^{-1} of nitrogen appears to be most appropriate for pesticide-free maize production in smallholder farms when alexandergrass is present. At this nitrogen level, the economic threshold should be determined using weed density, leaf area, soil cover, and dry matter. On average, weed control should be performed when alexandergrass density reaches between 10 and 15 plants m^{-2}, corresponding to approximately 21 days after maize emergence.

Acknowledgments

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