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INTEGRATED EFFECTS OF MULCHING AND NITROGEN MANAGEMENT ON MAIZE PHENOLOGY AND WEED SUPPRESSION UNDER SEMIARID CONDITIONS

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Article Info

Abstract

Maize (*Zea mays* L.) is a major cereal crop in Pakistan, yet its productivity in semiarid regions is constrained by nutrient limitations, weed competition, and poor soil health. This study evaluated the combined effects of mulching sources and integrated nitrogen (N) management on maize phenology, growth, and weed dynamics at the Agronomy Research Farm, University of Agriculture Peshawar, during 2022 and 2023. A split-plot randomized complete block design with three replications was used, with mulching (control, sugarcane bagasse, chickpea residue, live mulch) as the main plot factor and nitrogen regimes (control, 100% urea, 100% farmyard manure, 100% poultry manure, and integrated combinations supplying 150 kg N ha^{-1}) as subplots. Results indicated that live mulch and chickpea residue delayed tasseling and silking, while 100% urea and 50% urea + 50% FYM prolonged physiological maturity. Crop height and crop density were greatest under live mulch with 100% urea, reflecting improved crop vigor. Weed suppression was most effective with live mulch, which reduced weed density (15 m^{-2}) and biomass compared with control plots (21.7 m^{-2} and 191.4 g m^{-2} fresh weight). Urea-based treatments promoted higher weed biomass, whereas integrated organic–inorganic combinations moderated weed growth while sustaining crop performance. It is concluded that the integration of live mulch with balanced nitrogen management is an effective strategy to improve crop phenology and suppress weeds under semiarid conditions of Peshawar.

Keywords:

Maize, mulching, nitrogen management, phenology, weed suppression, semiarid conditions.

INTRODUCTION

Maize (Zea mays L.) is a globally important cereal crop that supplies food, feed and industrial raw material; its grain is rich in starch (~74%), protein (~11%) and oil (~4.7%), which underpins its central role in agro-food systems worldwide (Watson, 2003). Global maize production is concentrated in the Americas and Asia, with considerable socio-economic reliance on the crop in developing regions where a larger share of maize is used directly for human food (Shiferaw et al., 2011). In Pakistan, maize cultivation has expanded substantially and constitutes an important contributor to agricultural value-addition and regional food security (GoP, 2023). Despite advances in breeding and hybrid technology that have driven large yield gains over the past century, maize productivity in semiarid systems remains constrained by sub-optimal nutrient management, water stress and weed competition (Ali et al., 2012). In water-limited environments, agronomic practices that conserve soil moisture and improve root water uptake can substantially increase yields; mulching has been widely shown to moderate soil temperature, reduce evaporation, increase infiltration, and hence improve soil water status and root function (Ram et al., 2013). Organic mulches additionally contribute to soil organic matter, porosity and biotic activity during decomposition, providing both physical and biological benefits to the crop (Lal, 1998).

Nitrogen (N) is the primary macronutrient limiting maize growth and yield: it is integral to chlorophyll, amino acids and proteins, and strongly influences vegetative growth, reproductive development and final grain yield (Ciampitti et al., 2011). However, N dynamics are affected by source, timing and method of application, and exclusive reliance on inorganic N fertilizers can reduce some aspects of soil health (Ju et al., 2006). Integrated nitrogen management—combining inorganic fertilizers with organic amendments such as farmyard manure or poultry manure—has been advocated to sustain productivity while improving soil organic carbon and nutrient availability (Dawe et al., 2003). Split application of N and balanced fertilizer strategies can also improve nitrogen use efficiency (NUE) and reduce environmental losses (Fageria et al., 2005). Weed pressure represents a persistent biotic constraint in maize; weeds compete for light, water and nutrients, reduce plant stand and kernel set, and can substantially diminish yield (Teasdale, 1996). Mulching provides an effective non-chemical weed suppression strategy by shading the soil surface, acting as a physical barrier, and in some cases exerting allelopathic effects that reduce weed emergence and biomass (Singh et al., 1993). Live mulches (cover crops grown concurrently with the main crop) and residue mulches have been repeatedly reported to lower weed density and biomass, thereby reducing dependency on herbicides in conservation and low-input systems (Bilalis et al., 2010). Phenological development (timing of tasseling, silking and physiological maturity) is sensitive to both soil environment and nutrient availability. Practices that alter soil temperature and moisture such as mulching—or change nitrogen supply can shift phenological timelines, with consequences for kernel set, anthesis-silking interval and yield formation (Andrade et al., 1999). Understanding how mulching and integrated nitrogen management interacts to influence maize phenology and weed dynamics is therefore important for optimizing agronomic packages suited to semiarid environments.

Building on these premises, the present study investigated the integrated effects of mulching sources and seven nitrogen management regimes on maize phenological development, weed parameters under semiarid conditions at the Agronomy Research Farm, University of Agriculture Peshawar. The work aimed to identify combinations that (i) suppress weeds and improve maize phenology, (ii) enhance nitrogen use efficiency and soil health, and (iii) inform seed storage recommendations for improved seed vigor and longevity.

Materials and Methods

Experimental Design and Treatments

A split-plot randomized complete block design (RCBD) with three replications was used for the field experiments. Mulching sources were assigned to main plots and nitrogen management regimes to subplots. Plot dimensions were 4.0 m × 3.5 m, comprising five rows 3.0 m long with 70 cm row spacing. Maize hybrid CS-200 was sown at a seed rate equivalent to 30 kg ha^{-1}. Recommended P (100 kg ha^{-1} as SSP) and K (60 kg ha^{-1} as SOP) were applied at land preparation; P and K contributions from organic amendments were adjusted by reducing SSP and SOP accordingly. Urea (when used) was applied in two splits: at sowing and before first irrigation. Agronomic operations were uniform across treatments.

Factor A — Mulching sources (main plots):

- M1 = Control (no mulch)
- M2 = Sugarcane bagasse (thick residue mulch)
- M3 = Chickpea residue (thin residue mulch)
- M4 = Live mulch (Sesbania macrocarpa L., grown concurrently with maize).

Factor B — Nitrogen management (applied to supply 150 kg N ha^{-1}):

- N1 = Control (no N)
- N2 = 100% Urea
- N3 = 100% Farmyard manure (FYM)
- N4 = 100% Poultry manure (PM)
- N5 = 50% Urea + 50% FYM
- N6 = 50% Urea + 50% PM
- N7 = 50% FYM + 50% PM.

Treatment Application

Residue mulches (sugarcane bagasse and chickpea residue) were applied to the respective plots at sowing; the quantity of residue applied was matched to the amount of live mulch biomass obtained from the pilot production plots to allow comparability. Sesbania was established and maintained as live mulch in M4 plots. Organic and inorganic N sources were adjusted to supply the targeted 150 kg N ha^{-1} per treatment; the deficit N (based on initial soil N analysis) was supplemented from the respective treatment sources.

Crop Management

Land preparation and sowing were performed at appropriate moisture conditions. Standard weed, irrigation and pest management practices were applied uniformly across plots except where mulches contributed to weed suppression. A wheat crop was grown in the off-season without treatment application to avoid leaving land fallow (not part of the present experiments)

Phenological Observations

Phenological stages were recorded on a per-plot basis as follows:

- **Days to tasseling:** days from sowing until ~80% of plants in the plot produced visible tassels.
- **Days to silking:** days from sowing until ~80% of plants in the plot showed silk emergence.
- **Days to physiological maturity:** days from sowing until ~80% of plants reached physiological maturity.

These stage endpoints (80% criterion) were used to reduce within-plot variability and are the basis for all phenology measures reported. Plant height and plant stand (plants ha^{-1} at harvest) were also recorded to support interpretation of phenological effects.

Weed Sampling and Biomass Determination

Weed assessments were conducted twice per season: at the 5–6 leaf stage of maize and again two weeks later.

- **Sampling unit:** a 50 × 50 cm iron quadrat placed at two randomly located positions within each subplot.
- **Weed density (number m^{-2}):** all weeds inside the quadrat were counted and converted to number m^{-2}.
- **Weed fresh weight (g m^{-2}):** weeds inside the quadrat were uprooted, placed in labeled bags, and fresh weight recorded immediately.
- **Weed dry weight (g m^{-2}):** fresh samples were oven-dried at 105°C to constant weight and dry biomass recorded; values were converted to g m^{-2}.

Weed data from both sampling dates were used to calculate seasonal means and to test treatment effects. The quadrat protocol, sampling timing and drying procedure follow the methods used in the study.

Statistical Analysis

Data were analyzed using ANOVA appropriate for a split-plot RCBD with years included as a fixed effect (when combined analysis across seasons was performed). The main-plot factor was mulching (M) and the subplot factor was nitrogen management (N); key interactions (Y × M, Y × N, M × N, Y × M × N) were tested. When ANOVA showed significant treatment effects, mean separations were performed using the Least Significant Difference (LSD) test at the 5% probability level.

Results

Phenological Parameters

Mean data showed that mulching and nitrogen management significantly influenced the phenological development of maize across both years (Table 1). Year effect was evident, with tasseling, silking, and maturity occurring later in 2023 (55, 60, and 106 days, respectively) compared to 2022 (54, 59, and 103 days). Among mulching treatments, chickpea residue and live mulch delayed tasseling (55 days), while live mulch also prolonged maturity (106 days), followed by sugarcane bagasse (105 days); in contrast, control plots showed earlier tasseling (54 days) and maturity (104 days). Nitrogen management had a stronger influence on reproductive stages, where 100% urea consistently delayed tasseling (56 days), silking (61 days), and maturity (106 days), with similar maturity extension observed under 50% urea + 50% FYM. In contrast, the shortest durations for all phenological stages were recorded in the control (53, 58, and 103 days, respectively). Interactions among factors were mostly non-significant, except for Y × N, which significantly affected silking and maturity.

Table 1. Crop phenology as impacted by mulching source and integrated nitrogen management in 2022-2023.

Factor	Treatment	Days to tasseling	Days to silking	Days to Maturity
Mulching (M)	Control	54 b	59	104 c
	Sugarcane bagasse	54 b	59	105 b
	Chickpea residue	55 a	60	104 c
	Live mulch	55 a	60	106 a
Significance		*	NS	**
Nitrogen (N)	Control	53 d	58 d	103 d
	100% urea	56 a	61 a	106 a
	100% FYM	54 c	60 b	105 b
	100% poultry manure	54 c	60 b	105 b
	50% urea + 50% FYM	54 c	60 b	106 a
	50% urea + 50% PM	55 b	60 b	105 b
	50% FYM + 50% PM	54 c	59 c	104 c

Significance		***	***	**
Year means	2022	54 b	59 b	103 b
	2023	55 a	60 a	106 a
Significance		*	*	***
Interactions	Y × M	NS	NS	NS
	Y × N	NS	**	**
	M × N	NS	NS	NS
	Y × M × N	NS	NS	NS

Means followed by different letters in a column differ significantly at $p < 0.05$ (LSD). NS = not significant; * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001.

Crop Height (cm) and Crop Stand (ha^{-1})

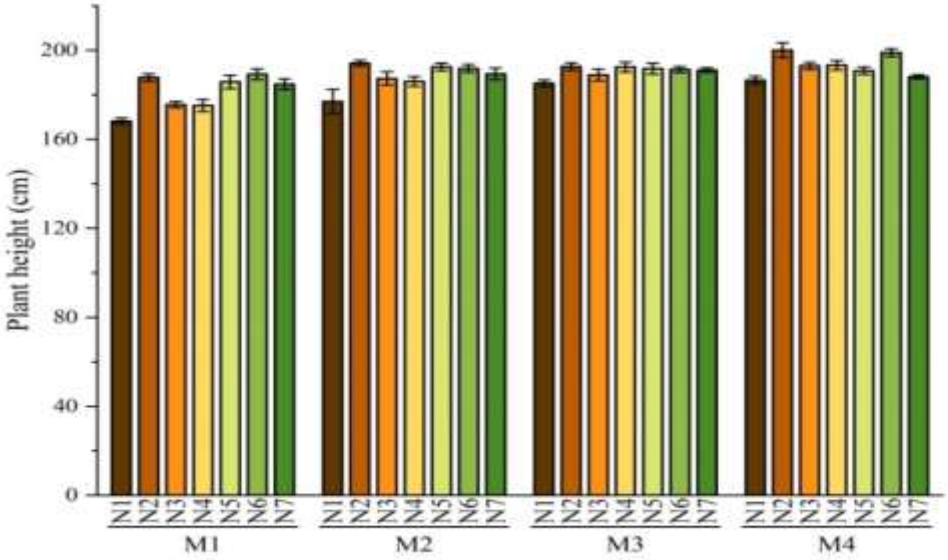
Mean data showed that both mulching and nitrogen management significantly influenced maize growth in terms of plant height and plant population at harvest across both years(Table 2). Plant height was greatest under live mulch (193.0 cm), followed by chickpea residue (190.5 cm) and sugarcane bagasse (188.3 cm), whereas the shortest plants occurred in the control (180.9 cm). For nitrogen management, the tallest plants were recorded with 100% urea (193.7 cm) and 50% urea + 50% poultry manure (192.9 cm), followed by 50% urea + 50% FYM (190.2 cm), while the control produced the shortest plants (179.2 cm). Similarly, plant population at harvest was higher in 2023 (64249 ha^{-1}) than in 2022 (62690 ha^{-1}). Among mulches, chickpea residue (64435 ha^{-1}) and live mulch (63980 ha^{-1}) maintained the highest stand counts, while the lowest was noted in the control (62305 ha^{-1}). In nitrogen treatments, the maximum plant population was observed with 100% urea (65829 ha^{-1}), followed by 50% urea + 50% poultry manure (65048 ha^{-1}) and 50% urea + 50% FYM (63671 ha^{-1}), whereas the control produced the fewest plants (61283 ha^{-1}). Interactive responses further revealed that the combination of live mulch with 100% urea consistently produced the tallest plants and the highest plant population at harvest (Figure 1).

Table 2. Crop height (cm) and stand (ha^{-1}) as impacted by mulching source and integrated nitrogen management in 2022-2023.

Factor	Treatment	Crop height (cm)	Crop stand (ha^{-1})
Mulching (M)	Control	180.9 c	62305 c
	Sugarcane bagasse	188.3 b	63159 b
	Chickpea residue	190.5 ab	64435 a
	Live mulch	193.0 a	63980 a
Significance		**	***
Nitrogen (N)	Control	179.2 d	61283 e
	100% urea	193.7 a	65829 a
	100% FYM	186.2 c	62838 d
	100% poultry manure	186.8 c	62942 d
	50% urea + 50% FYM	190.2 b	63671 c

	50% urea + 50% PM	192.9 a	65048 b
	50% FYM + 50% PM	188.3 bc	62678 d
Significance		***	***
Year means	2022	186.25	62690 b
	2023	190.13	64249 a
Significance		NS	***
Interactions	Y × M	NS	NS
	Y × N	NS	*
	M × N	**	***
	Y × M × N	NS	**

Means followed by different letters in a column differ significantly at $p < 0.05$ (LSD). NS = not significant; * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001.



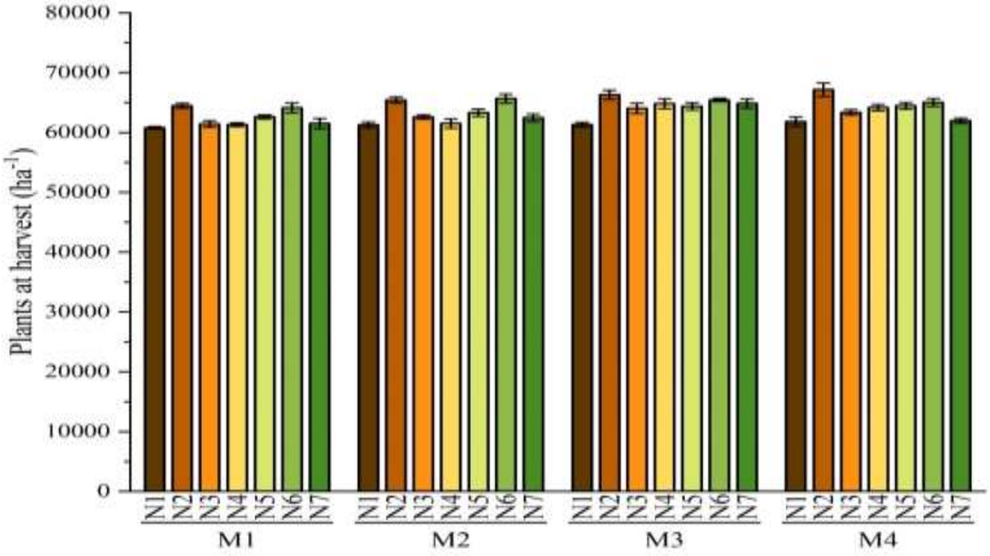


Figure 2. Combine effect of mulching and nitrogen management on crop height (cm) and crop stand (ha^{-1}) in 2022 and 2023. Error bar presented are the standard error means of replications (n = 6). Factor A represents Mulching Sources: M1 = Control; M2 = Thick mulch (sugarcane bagasse); M3 = Thin mulch (chickpea residue); M4 = Live mulch (Sesbania macrocarpa L.). Factor B represents Nitrogen Management: N1 = Control; N2 = 100% Urea; N3 = 100% Farmyard manure; N4 = 100% Poultry manure; N5 = 50% Urea + 50% FYM; N6 = 50% Urea + 50% PM; N7 = 50% FYM + 50% PM. Nitrogen was applied at a rate of 150 kg ha^{-1}, with urea administered in split doses.

Weeds Density (m^{-2}) and Weed Biomass (gm^{-2})

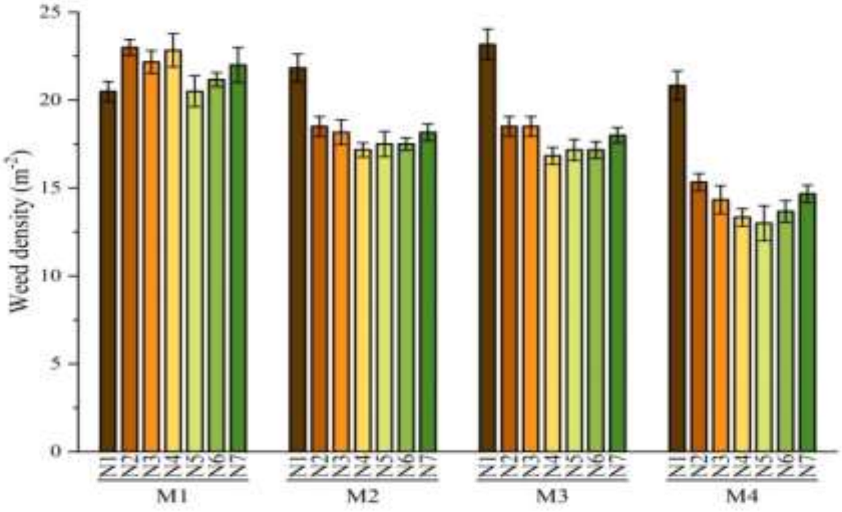
Mean data showed that mulching and nitrogen management considerably influenced weeds density and biomass in the maize field across both years (Table 3). Weed density was highest in the control plots (21.7 m^{-2}), followed by sugarcane bagasse (18.4 m^{-2}) and chickpea residue (18.5 m^{-2}), while the lowest density was observed under live mulch (15.0 m^{-2}). In nitrogen treatments, the greatest weed density was recorded in the control (21.6 m^{-2}) and 100% urea (18.8 m^{-2}), whereas the lowest occurred in 50% urea + 50% FYM (17.0 m^{-2}). Weed fresh weight followed a similar trend, being highest in the control (191.4 g m^{-2}), chickpea residue (126.4 g m^{-2}), and sugarcane bagasse (102.7 g m^{-2}), and lowest under live mulch (78.1 g m^{-2}). Among nitrogen regimes, 100% urea (131.5 g m^{-2}) produced the heaviest weed biomass, while the control (120.3 g m^{-2}) showed the least. Weed dry weight also varied significantly, with maximum values in the control (53.1 g m^{-2}) and chickpea residue (34.7 g m^{-2}), while the lowest were observed in sugarcane bagasse (18.9 g m^{-2}) and live mulch (12.4 g m^{-2}). For nitrogen management, 100% urea (33.3 g m^{-2}) and 50% urea + 50% poultry manure (31.4 g m^{-2}) maintained the greatest dry weights, while the control recorded the lowest (26.0 g m^{-2}). Interactive responses revealed that control plots, and in some cases urea-based treatments, produced the highest weed density and biomass, while mulching, particularly live mulch, was most effective in suppressing weed growth (Figure 2).

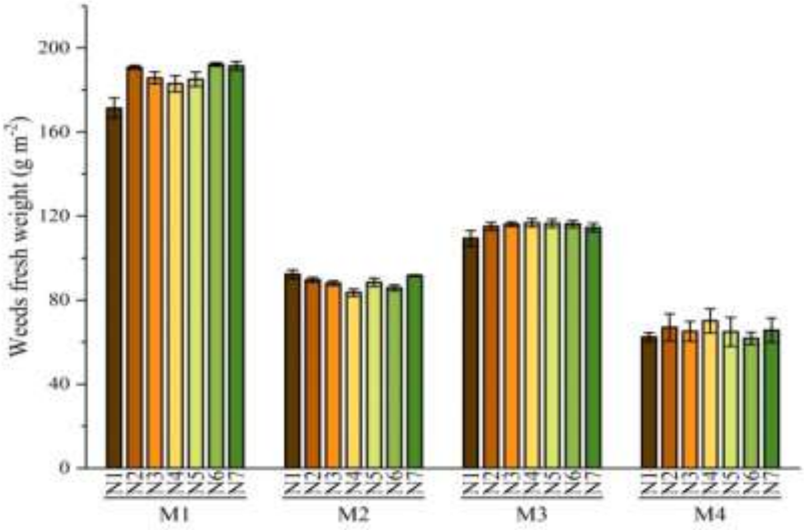
Table 3. Weeds density (m^{-2}) and biomass (g m^{-2}) as impacted by mulching source and integrated nitrogen management in 2022-2023.

Factor	Treatment	Weed density (m^{-2})	Weed fresh weight (g m^{-2})	Weed dry weight (g m^{-2})
Mulching (M)	Control	21.7 a	191.4 a	53.1 a
	Sugarcane bagasse	18.4 b	102.7 c	18.9 c
	Chickpea residue	18.5 b	126.4 b	34.7 b
	Live mulch	15.0 c	78.1 d	12.4 c
Significance		**	***	***
Nitrogen (N)	Control	21.6 a	120.3 c	26.0 b
	100% urea	18.8 b	131.5 a	33.3 a
	100% FYM	18.3 bc	123.1 bc	29.4 ab
	100% poultry manure	17.5 bc	122.7 bc	28.8 ab
	50% urea + 50%	17.0 c	123.1 bc	29.5 a

	FYM			
	50% urea + 50% PM	17.4 bc	125.7 b	31.4 a
	50% FYM + 50% PM	18.2 bc	126.0 b	30.2 ab
Significance		***	**	**
Year means	2022	18.8	132.9	30.9
	2023	18.0	116.4	28.6
Significance		NS	NS	NS
Interactions	Y × M	NS	***	NS
	Y × N	NS	NS	NS
	M × N	***	***	**
	Y × M × N	NS	NS	NS

Means followed by different letters in the same column differ significantly at $p < 0.05$ (LSD). NS = not significant; ** = significant at 0.01; *** = significant at 0.001.





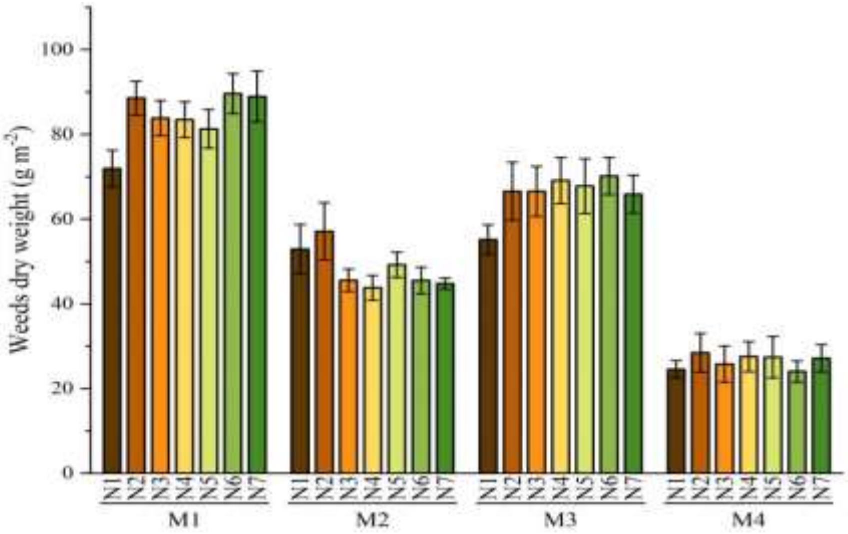


Figure 2. Combine effect of mulching and nitrogen management on weeds density (m^{-2}) and weed biomass ($g\ m^{-2}$) in 2022 and 2023. Error bar presented are the standard error means of replications (n = 6). Factor A represents Mulching Sources: M1 = Control; M2 = Thick mulch (sugarcane bagasse); M3 = Thin mulch (chickpea residue); M4 = Live mulch (Sesbania macrocarpa L.). Factor B represents Nitrogen Management: N1 = Control; N2 = 100% Urea; N3 = 100% Farmyard manure; N4 = 100% Poultry manure; N5 = 50% Urea + 50% FYM; N6 = 50% Urea + 50% PM; N7 = 50% FYM + 50% PM. Nitrogen was applied at a rate of 150 kg ha^{-1}, with urea administered in split doses.

Discussion

The phenological development of maize, including tasseling, silking, and physiological maturity, is regulated by environmental cues and agronomic inputs such as nitrogen supply and mulching. In this study, nitrogen significantly influenced tasseling and silking, while mulching affected tasseling only. Higher nitrogen inputs (100% urea and integrated treatments like 50% urea + 50% poultry manure) delayed tasseling and silking by enhancing vegetative vigor, photosynthetic capacity, and nutrient status, whereas nitrogen-deficient plants flowered earlier as a survival mechanism, consistent with the findings of Yohannes et al. (2024) and Asibi et al. (2019). A narrower anthesis-silking interval (ASI) under higher nitrogen suggested balanced floral development, favorable for pollination and kernel set. Mulching delayed tasseling through improved soil moisture retention and moderated soil temperatures but had little effect on silking, as accumulated growing degree days overrode mulch-induced delays, aligning with the observations of Kader et al. (2019) and Ibrahim and Khan et al. (2024). The interaction between nitrogen and mulching was non-significant, indicating additive effects, while year-to-year climatic variability delayed tasseling and silking in 2023 compared to 2022 due to cooler conditions and moisture variability, as also reported by Liu et al. (2013). Physiological maturity was delayed under higher nitrogen and mulching, with nitrogen extending maturity by enhancing chlorophyll content, delaying senescence, and prolonging the grain-filling period through sustained photosynthetic activity and carbohydrate translocation (Ciampitti and Vyn, 2012), whereas nitrogen-deficient conditions accelerated senescence and reduced effective grain-filling duration (Tollenaar and Lee, 2002). Integrated nutrient management (e.g., 50% urea + 50% FYM or poultry manure) performed comparably to full urea application in delaying maturity, suggesting gradual nutrient release and better synchronization with crop demand, supported by Ghosh et al. (2004). Mulching further prolonged maturity, with live mulch producing the longest delay, followed by sugarcane bagasse, by conserving soil moisture, reducing thermal fluctuations, and moderating respiration rates (Kader et al., 2019). Live mulch also contributed additional nitrogen through biological fixation and organic matter decomposition, reinforcing nitrogen's role in prolonging the life cycle, while control and chickpea residue treatments matured earlier due to their limited capacity to buffer soil microclimate and sustain growth.

Crop height and crop stand at harvest in maize were greatly influenced by mulching and nitrogen management, with results highlighting the combined roles of nutrient supply, soil microclimate, and climatic variability in shaping crop performance. The tallest plants (193.0 cm) were observed under live mulch, which improved rhizosphere conditions by moderating soil temperature, conserving moisture, suppressing weeds, and enhancing microbial activity, thereby facilitating better nutrient uptake and shoot elongation (Kader et al., 2019). Nitrogen further contributed to increased plant height, with maximum values recorded under 100% urea and 50% urea + 50% poultry manure, consistent with nitrogen's role in chlorophyll biosynthesis, cell division, and prolonged vegetative growth (Ciampitti and Vyn, 2012). The tallest plants resulted from the combined treatment of live mulch and 100% urea, reflecting improved nitrogen-use efficiency (NUE) through reduced volatilization and leaching losses, supported by earlier findings that mulching enhances nitrogen retention and uptake (Brar and Kaur, 2016; Ma et al., 2018). Similarly, plant population at harvest was significantly affected by both factors, with higher populations in 2023 than 2022 due to more favorable climatic conditions for emergence and survival (Hatfield and Prueger, 2015). Among mulching treatments, live mulch and chickpea residue maintained higher plant populations by stabilizing soil temperature, conserving moisture, and reducing competition, with leguminous mulches providing additional nitrogen benefits (Teasdale and Mohler, 2000; Kader et al., 2019). Nitrogen management also played a key role, with highest plant numbers under 100% urea and integrated treatments (50% urea + 50% poultry manure), where organic-inorganic combinations improved nutrient synchronization and early seedling vigor (Yadav et al., 2003). The lowest populations were recorded in the control plots due to nitrogen deficiency and unfavorable soil conditions. Importantly, the significant interaction between mulching and nitrogen (M × N), particularly live mulch with 100% urea, demonstrated the synergistic effects of improved microclimate and nutrient supply in ensuring optimal plant establishment and retention, underscoring the value of integrated crop management for sustaining plant density and maximizing yield potential (Biswas et al., 2024).

Weed density and biomass (fresh and dry weights) in maize were significantly influenced by mulching and nitrogen management, with their interaction (M × N) also emerging significant, underscoring the importance of integrated crop management in weed suppression. Across mulching treatments, live mulch consistently recorded the lowest weed density and biomass due to its superior physical and biological suppression mechanisms, including shading that reduces light penetration, physical interference with weed emergence, and potential allelopathic effects, as also noted by Jamshidi et al. (2013). In contrast, control plots without mulch showed the highest weed density and biomass because bare soil facilitates weed seed germination and growth, while sugarcane bagasse and chickpea residue provided moderate suppression. Nitrogen management also played a pivotal role, with the no-nitrogen control having high weed density due to reduced crop vigor and canopy closure that allowed greater light availability for weeds (Teasdale and Mohler, 2000; Liebman and Davis, 2000). Integrated and organic treatments such as 50% urea + 50% FYM and 100% poultry manure significantly reduced weed density and biomass by promoting gradual nutrient release, enhancing crop competitiveness, and improving soil properties (Raviv, 2010). In contrast, 100% urea treatments resulted in moderately higher weed density and biomass compared to organic or integrated systems, reflecting the stimulation of nitrophilous weeds under readily available nitrogen, as reported by Blackshaw et al. (2003). For weed fresh and dry weights, live mulch again exerted the strongest suppressive effect by physically shading soil, competing for resources, and limiting weed vigor (Bhaskar et al., 2021), while residue mulches provided partial suppression and the control allowed maximum weed growth. Urea-based treatments generally promoted higher weed biomass due to rapid nitrogen availability favoring both crop and weeds, while organic amendments synchronized nutrient release with crop demand, reducing early-season weed flushes. The interactive effects of mulching and nitrogen revealed that mulch alone was insufficient under nitrogen-deficient conditions, while the combination of live mulch with organic or integrated nitrogen sources provided the most effective weed suppression through a synergistic blend of crop competitiveness, moderated nutrient release, shading, and allelopathy, consistent with the findings of Murungu et al. (2011) and Bilalis et al. (2010).

Conclusion

The study demonstrated that mulching and integrated nitrogen management significantly influenced maize growth, phenology, and weed suppression. Live mulch combined with balanced nitrogen inputs proved most effective for reducing weed pressure and enhancing crop vigor. Urea-based treatments increased weed biomass, while integrated organic–inorganic regimes provided sustainable outcomes. Overall, integrating live mulch with nitrogen management offers a promising approach to improve maize productivity and soil health in semiarid systems.

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