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EVALUATION OF HERBICIDE EFFICACY ON GROWTH INDICES OF MAIZE CULTIVATED UNDER CONSERVATION AGRICULTURE SYSTEM

Bharat Bhushan Rana[1], Vinod Sharma[1], Sandeep Manuja[1], Sanjay Kumar Sharma[2], Akashdeep Singh[1&3]*, Rahul Sharma[1] and Garima Chauhan[1]*

[1]Department of Agronomy, CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur, H.P., India

[2]Department of Soil Science, CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur, H.P., India

[3]Faculty of Agriculture, School of Agricultural Sciences, Nirwan University, Jaipur, Rajasthan, India

*Corresponding authors E-mail: akash.agercultura@gmail.com, garimac2010@gmail.com

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ABSTRACT

Conservation agriculture involves minimum disturbance of soil resulting in excessive weed competition. In such a scenario, chemical control of herbicides without compromising with yield becomes necessary. In the present study, we investigated the efficacy of different herbicides applied days before crop sowing in combination with post-emergence herbicides applications on the growth indices of maize crop. The application of non-selective herbicides ensured that field is free from any weeds and becomes ideal for sowing. This practice was done to avoid tillage operation which is a significant component of conservation agriculture. Results revealed that plant height and growth indices were higher when glyphosate was used during pre-field/sown operations followed by various post-emergent herbicides. Suboptimal control was observed with flame weeding pre-sown operations, even when same set of post-emergence herbicides were used and most of these treatments were at par with conventional practice. The study concludes that pre-field/sown operation application of glyphosate @ 1.5 kg ha^{-1} followed by post-emergence spray of tembotrione @ 120 g ha^{-1} (20-30DAS) would result in significantly taller plants and better growth indices though this treatment was found to be at par with application of glyphosate @ 1.5 kg ha^{-1} during pre-sown operation followed by post-emergent application of topramezone @ 25.2 g ha^{-1} (20-30 DAS).

***Keywords* :** Herbicide efficacy, growth indices, maize, conservation agriculture system.

Introduction

Maize (*Zea mays* L.) is third most import cereal and staple food crop after rice and wheat worldwide, while the grain/seed yield of crop is dependent on the agrometeorological conditions. In context of crop cultivation, management practices such as weed management play a significant role in reducing the yield loss. Weed induced yield loss is primarily due to direct competition for space, nutrients, light, water and carbon dioxide. Studies have reported 50-75% yield loss due to weeds or late season control of weeds (Singh *et al*., 2020; Soltani *et al*., 2016; Landau *et al*., 2021). The loss is concerning at a time when India is planning to boost the mixing of petrol with 20% ethanol under the National Policy on Biofuels. For a broader perspective and importance of maize, corn ethanol production in United States increased from 6.1 billion liters to 57 billion liters (Lee *et al*., 2021). Therefore, optimizing weed management strategies is must to ensure optimal growth and yield of maize while maintaining sustainability of production system.

Conservation agriculture production system has emerged as an alternative to conventional practice to reduce the emergence of weeds by not turning soil (zero-tillage) and maintaining permanent soil cover. Associating this production system with chemical control can further improve control of weed population. Moreover, conservation agriculture practices, such as retention of crop residues and nutrient management, have been found to enhance the efficiency of herbicidal treatments by creating a more favourable microenvironment for maize growth (Mhlanga *et al*., 2016). Growth indices are critical indicators of plant health and performance under different agronomic conditions (Naik *et al*., 2024; Shahu *et al*., 2024). These indices are directly influenced by the competitive interaction between crops and weeds. Herbicides, by mitigating weed pressure, allow for improved growth indices, which are essential for achieving higher yields. In maize, growth indices are highly sensitive to weed control measures, with significant improvements observed when effective pre and post emergence herbicides are applied (Balaji *et al*., 2023). These indices also serve as a measure of how well crops utilize available resources such as light, water and nutrients in the presence or absence of competition from weeds.

Materials and Methods

The field experiments were conducted during the *kharif* seasons of 2022 and 2023 at Experimental farm of Hill Agricultural Research and Extension Centre (HAREC)-CSK Himachal Pradesh Krishi Vishvavidyalaya, Bajaura, Kullu, Himachal Pradesh, India. The experimental site is situated at an elevation of 1556 m AMSL with latitude 31°8' N and longitude of 77° E. The experiment was laid out in a randomized complete block design with 18 treatments and three replications. The treatments were divided into pre-field preparation followed by different post-emergence herbicide applications. The pre-field operations were performed 15 days before sowing for treatments T_1-T_5, 21 days before sowing for treatments T_6-T_{10} and 5 days before sowing for treatments T_{11}-T_{15}. In some of the treatments, intercropping was done with horsegram (*kulthi*) to cover the space between two rows as means to reduce the weed stress. For this purpose, variety VLG 1 of horsegram was used in the study. The details of the treatment have been presented in Table 1. The maize variety *Him Palam* Maize Composite 1 (L 315) was used with a seed rate of 20 kg ha^{-1}. The row to row spacing was kept at 60 cm while plant to plant spacing of 20 cm was maintained. The soil was silty loam in texture, slightly acidic in reaction, low in available nitrogen, high in available phosphorus and medium in available potassium.

Table 1: Details of treatment

Treatments	Offseason	In maize
Trt_1	Paraquat (0.75 kg/ha)	Tembotrione (120 g/ha) (20-30 DAS)
Trt_2	Paraquat (0.75 kg/ha)	Mesotrione (90 g/ha) (20-30 DAS)
Trt_3	Paraquat (0.75 kg/ha)	Halosulfuron (90 g/ha) (20-30 DAS)
Trt_4	Paraquat (0.75 kg/ha)	Topramezone (25.2 g/ha) (20-30 DAS)
Trt_5	Paraquat (0.75 kg/ha)	Intercropping (Kulthi) with metolachlor (pre-emergence)
Trt_6	Glyphosate (1.5 kg/ha)	Tembotrione (120 g/ha) (20-30 DAS)
Trt_7	Glyphosate (1.5 kg/ha)	Mesotrione (90 g/ha) (20-30 DAS)
Trt_8	Glyphosate (1.5 kg/ha)	Halosulfuron (90 g/ha) (20-30 DAS)
Trt_9	Glyphosate (1.5 kg/ha)	Topramezone (25.2 g/ha) (20-30 DAS)
Trt_{10}	Glyphosate (1.5 kg/ha)	Intercropping (Kulthi) with metolachlor (pre-emergence)
Trt_{11}	Flame weeding	Tembotrione (120 g/ha) (20-30 DAS)
Trt_{12}	Flame weeding	Mesotrione (90 g/ha) (20-30 DAS)
Trt_{13}	Flame weeding	Halosulfuron (90 g/ha) (20-30 DAS)
Trt_{14}	Flame weeding	Topramezone (25.2 g/ha) (20-30 DAS)
Trt_{15}	Flame weeding	Intercropping (Kulthi) with metolachlor (pre-emergence)
Trt_{16}	Conventional with pre-emergence weed control	Conventional with pre-emergence weed control
Trt_{17}	Weed Free	Weed Free
Trt_{18}	Weedy Check	Weedy Check

The absolute growth rate (AGR) (cm day^{-1}) was calculated using the formula given below.

$$AGR = \frac{H_2 - H_1}{t_2 - t_1}$$

Where, H_2 = plant height at time interval t_2

H_1 = plant height at time interval t_1

The crop growth rate (CGR) (g m^{-2} day^{-1}) was calculated using the formula given below.

$$CRG = \frac{W_2 - W_1}{\rho(t_2 - t_1)}$$

Where, W_2 = total dry matter of crop plant at the time interval t_2

ρ = ground area

W_1 = total dry matter of crop plant at the time interval t_1

The data was subjected to F-test followed by Duncan's paired comparison post-hoc test as prescribed by Gomez and Gomez (1984). The least significant difference (LSD) was evaluated using R-package 'agricolae'. The visualizations were generated using R-packages *viz.,* 'ggplot2', 'dplyr', 'metan' and 'magick'.

Results and Discussion

Plant height: The pre-field operations and herbicide treatments significantly influenced the plant height of maize. Significantly taller maize plants were observed under treatment where glyphosate was applied as pre-field operation followed by either tembotrione or topramezone as post-emergence herbicide (Trt_6 and Trt_9) (Table 2). Without any competition from weeds during the entire crop duration, weed free check (Trt_{17}) also resulted in taller plants. The response of tembotrione and topramezone (Trt_1 and Trt_4, respectively) was also observed under treatments where paraquat was used as pre-field operation though these treatments were found to be statistically at par with each other and with conventional practice of weed control (Trt_{16}) and pre-field herbicide application of glyphosate followed by post-emergence spray of mesotrione (Trt_7). The treatments where flame weeding was performed during pre-field operations resulted suboptimal weed control resulting in significantly smaller plants and were found to be at parity with weedy check treatment (Trt_{18}).

Glyphosate is a non-selective systemic herbicide which kills most of the plants/weeds due its absorption *via* plant parts resulting in blockage of shikimate pathway (Pfister and Urbach, 1983; Barbosa, 2020). The inhibition of this pathways disrupts production of aromatic amino acids essential for protein synthesis causing stunted plant growth, leaf discoloration and death of tissues (Dayan, 2019; Panigrahi *et al.*, 2021). Furthermore, this mode of action does not distinguish between annuals, biennials or perennials. Being systemic, it is able to act on the below-ground parts such as roots, rhizomes, stolon, etc. resulting in significant period of weed control. On the other hand, flame weeding action is limited to above-ground biomass. Without any significant effect on the roots or underground plant parts regrowth occurs between 7-14 days resulting in temporary control of weed population (Pull, 2022; Knezevic, 2023).

Table 2: Effect of herbicide treatments on plant height (cm) of maize during two years of study

Treatments	30 DAS		60 DAS		90 DAS		120 DAS	
	2022	2023	2022	2023	2022	2023	2022	2023
Trt_1	42.8	41.1	153.9	150.5	187.1	179.9	190.6	184.2
Trt_2	41.4	40.6	144.8	142.2	176.7	169.6	180.0	174.0
Trt_3	41.3	39.8	137.6	135.1	167.9	161.1	170.7	165.0
Trt_4	41.0	41.2	154.3	151.6	188.3	180.7	191.9	185.4
Trt_5	40.7	39.9	141.9	139.3	173.1	166.2	176.4	170.5
Trt_6	46.0	45.1	159.8	157.9	195.6	188.4	199.7	194.0
Trt_7	45.5	44.6	149.7	147.0	182.6	175.3	186.1	179.9
Trt_8	45.6	44.0	138.7	136.2	169.2	162.7	172.4	166.6
Trt_9	45.0	44.7	162.6	159.7	198.4	193.1	202.2	196.4

Trt_{10}	45.8	44.6	142.5	139.9	173.9	166.9	177.2	171.2
Trt_{11}	39.2	37.3	148.4	145.7	181.0	173.9	184.5	178.4
Trt_{12}	38.1	37.3	143.7	141.1	175.3	168.3	178.6	172.7
Trt_{13}	37.5	36.4	135.7	132.9	165.6	158.9	167.7	162.1
Trt_{14}	37.8	37.4	152.6	149.9	185.2	177.8	188.7	182.4
Trt_{15}	38.3	37.3	140.3	137.8	171.2	164.3	174.4	168.5
Trt_{16}	47.3	47.7	146.5	147.5	177.9	179.5	182.1	176.0
Trt_{17}	49.7	48.7	157.4	154.9	192.0	184.3	196.3	190.4
Trt_{18}	33.8	33.1	128.5	126.2	156.8	150.5	159.7	154.4
SEm±	0.72	0.78	2.43	2.34	2.61	2.53	2.71	2.66
LSD	2.06	2.24	6.98	6.72	7.51	7.28	7.78	7.64

Growth indices: The absolute growth rate (Fig. 1 & 2) and crop growth rate (Fig. 3 & 4) were found to be significantly influenced by different pre-field weed control operation and post-emergence herbicide treatments. Significantly higher AGR during early growth stage (0-30 DAS) was observed in treatments where glyphosate was used to eradicate weed during pre-field operations followed by application of post-emergence herbicides tembotrione, topramezone and mesotrione (Trt_6, Trt_9 and Trt_7, respectively). During the subsequent growth stages, glyphosate followed by tembotrione and topramezone gave significant results in terms of growth. During the growth period, the treatments comprising of flame weeding (Trt_{11-15}) during the pre-field operations resulting in significantly lower values for AGR and was found to be at par with weedy check (Trt_{16}). Weed free (Trt_{17}) treatment consistently exhibited higher AGR during both years.

Higher CGR during the initial growth phase (0-30 DAS) was observed under treatment (Fig. 3 & 4) where conventional tillage operations followed by pre-emergence application of herbicide (Trt_{16}) was done to control weed population. Though this treatment was at parity with weed free treatment. The treatments with glyphosate-based control during pre-field operations (Trt_6-Trt_{10}) showed higher CGR in comparison to flame weeding treatments and weedy check. During the subsequent growth stages, glyphosate application during pre-field operation followed by post-emergence herbicide application of topramezone gave notably higher CGR though this treatment was found to be at par with other glyphosate-based treatments. Since Absolute Growth Rate (AGR) and Crop Growth Rate (CGR) are influenced by plant height and dry matter accumulation, any factors affecting these parameters will directly impact growth indices (Seth and Kumar, 2019). Weeds typically grow more rapidly due to their strategy of prioritizing population expansion over quality development (van der Meulen and Chauhan, 2017). Consequently, they compete aggressively with crops for essential resources such as nutrients, water, light, and space, which can lead to significant yield losses. Higher AGR and CGR values are likely attributable to effective weed control achieved through the application of pre-emergence and post-emergence herbicides under conservation agriculture system (Singh *et al.*, 2024). This approach helps suppress weed populations during critical growth phases, allowing crops to utilize resources more efficiently. Numerous studies have established that the critical period for crop-weed competition generally occurs between 30-45 days after sowing (DAS) or during the initial one-fourth of the crop's growth cycle (Sinchana and Raj, 2023). In contrast, flame weeding only destroys the above-ground biomass of weeds, allowing for rapid regrowth from underground vegetative parts such as rhizome, stolon, suckers, etc (Ascard, 1995). This reduces the efficacy of post-emergence herbicides and leads to continued weed competition. Furthermore, flame weeding may inadvertently break seed dormancy in some weed species, thereby increasing weed emergence and competition for resources. These factors collectively contribute to the lower AGR and CGR observed with flame weeding compared to chemical herbicide treatments.

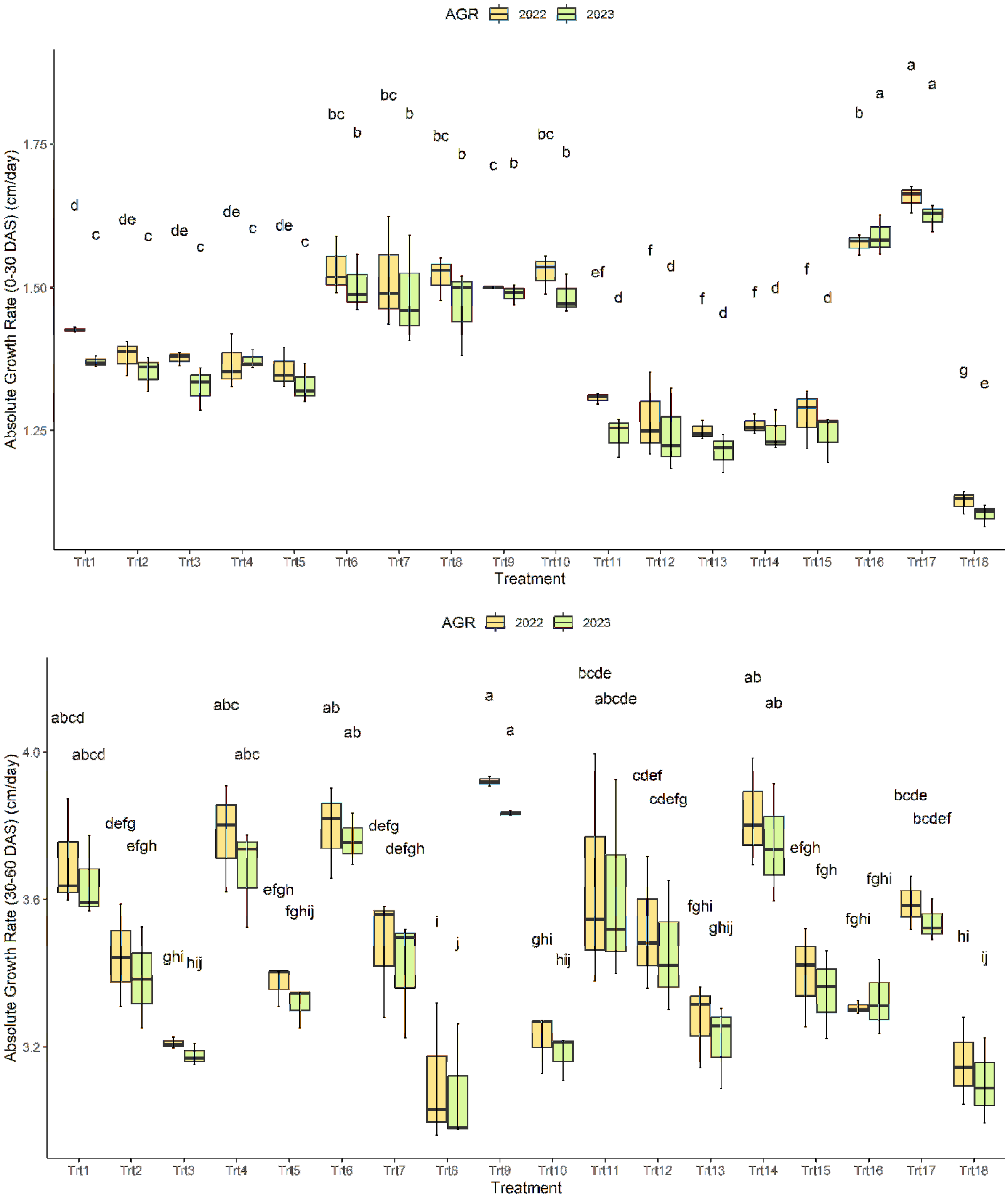

Fig 1: Effect of different herbicide treatments on absolute growth rate (cm day^{-1}) (30 & 60 DAS) during both years of study

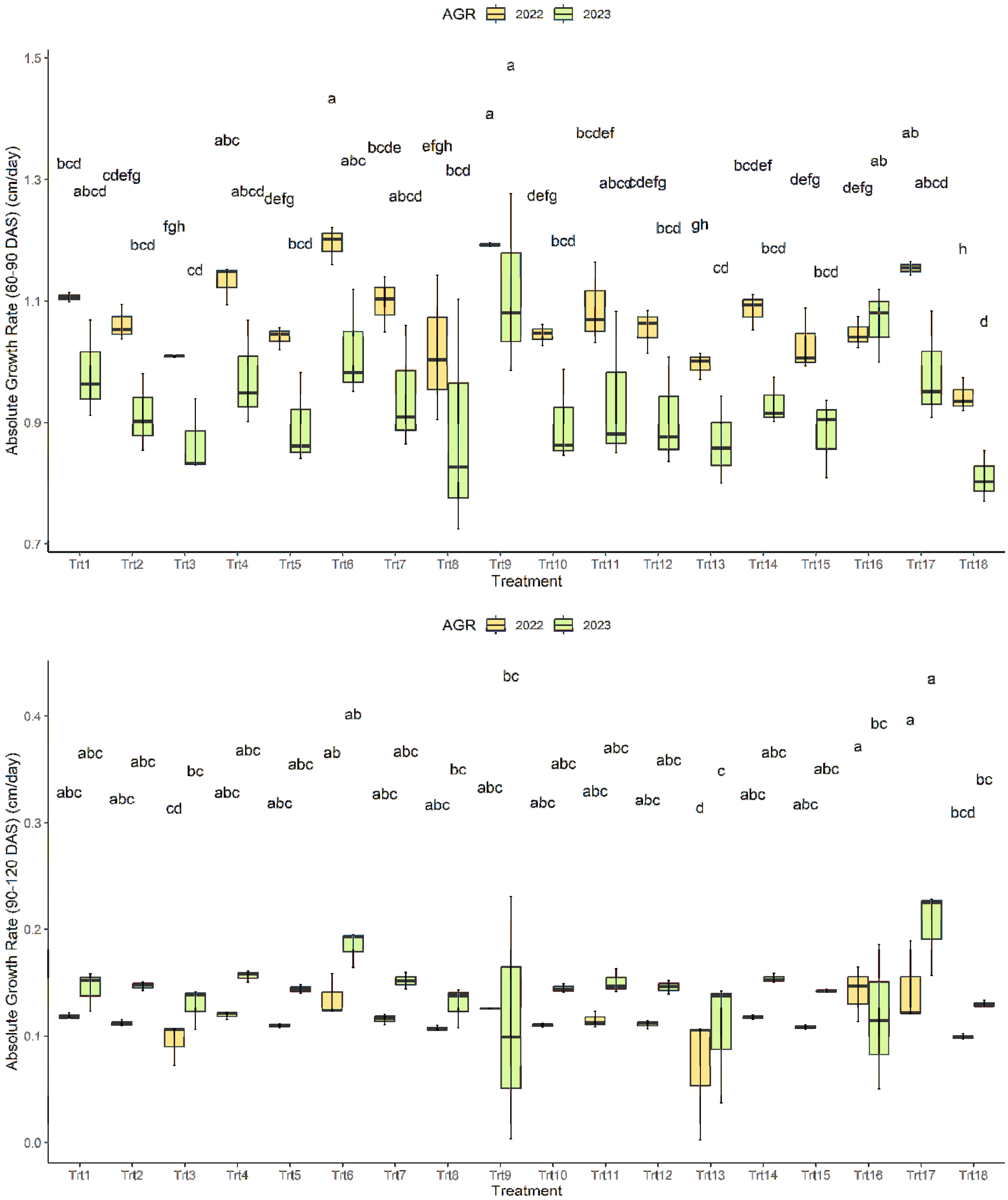

Fig 2: Effect of different herbicide treatments on absolute growth rate (cm day^{-1}) (90 & 120 DAS) during both years of study

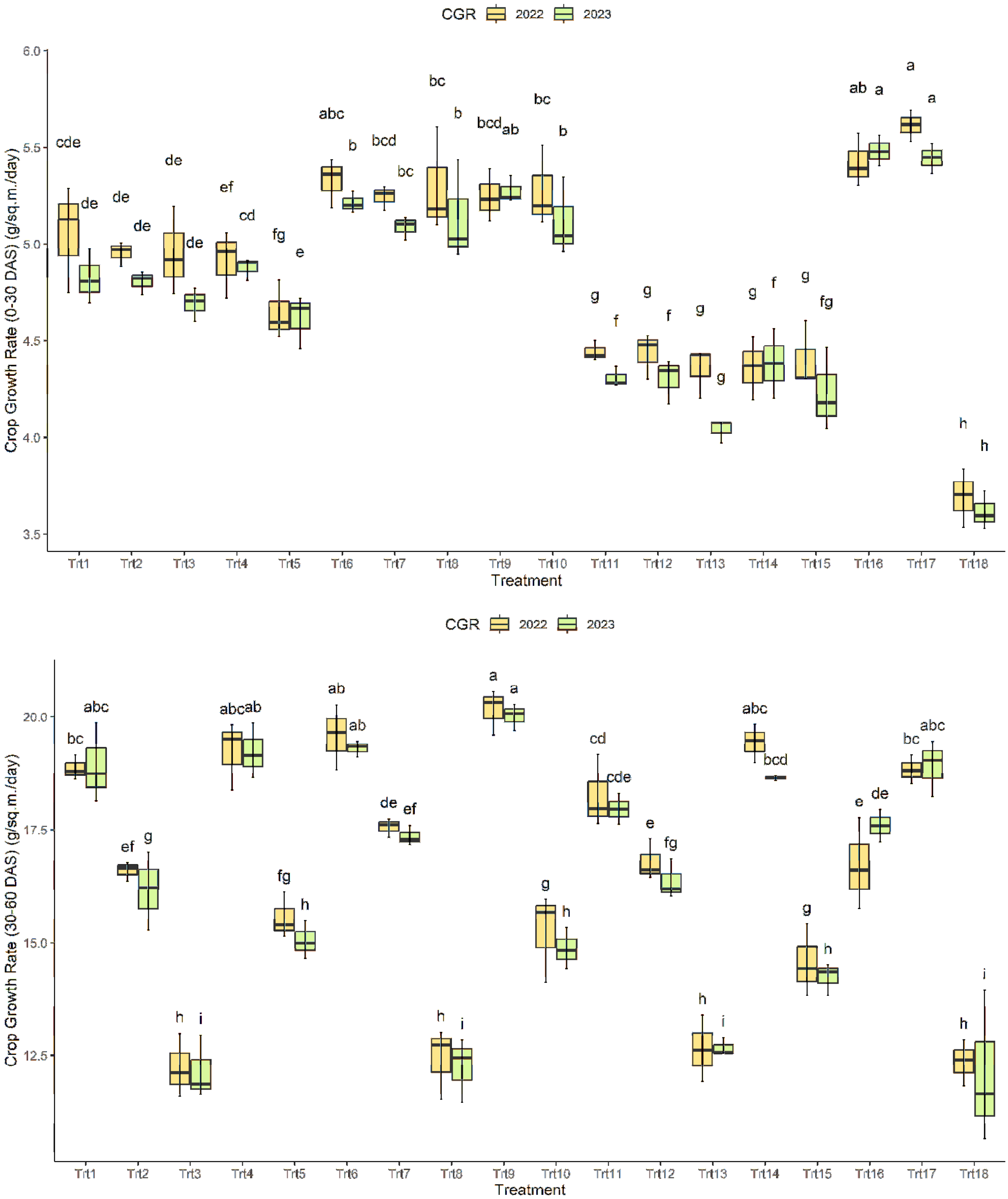

Fig 3: Effect of different herbicide treatments on crop growth rate (g m^{-2} day^{-1}) (30 & 60 DAS) during both years of study

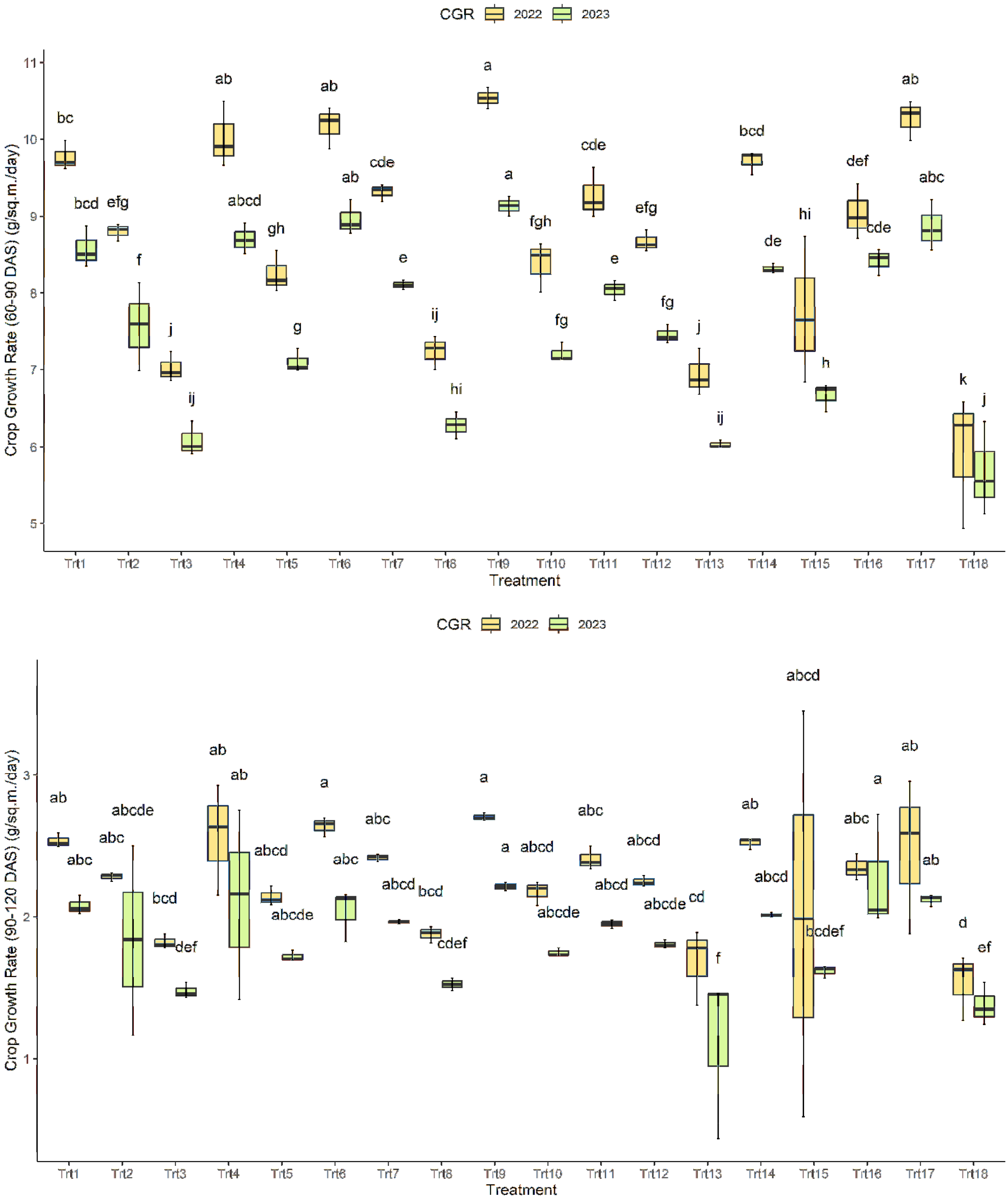

Fig 4: Effect of different herbicide treatments on crop growth rate (g m^{-2} day^{-1}) (90 & 120 DAS) during both years of study

Correlation analysis: The figure 5 depicts correlation among yield, growth indices and plant height of maize crop. Most of the parameters showed significant relation varying from very strong to moderate correlation. Grain yield was found to be strongly correlated to CGR (0.96 and 0.95) at 60 and 90 DAS suggesting that weed control during this period would significantly influence the grain yield. Moderate correlation was observed between grain yield and AGR, but more at 60 DAS (0.73) as compared to 90 DAS (0.54). Since AGR was calculated using plant height, therefore weed control till 60 DAS would result in taller plants and ultimately leading to higher grain yield. A strong correlation was also observed between plant height and CGR (60 and 90 DAS) (0.83 and 0.88) suggesting importance of optimum weed control for better availability of nutrients to the crop plants resulting in taller plants. Taller plants are able to smoother weed crops thereby competing more strongly with the weeds and improving their dry matter accumulation as suggested by the higher CGR.

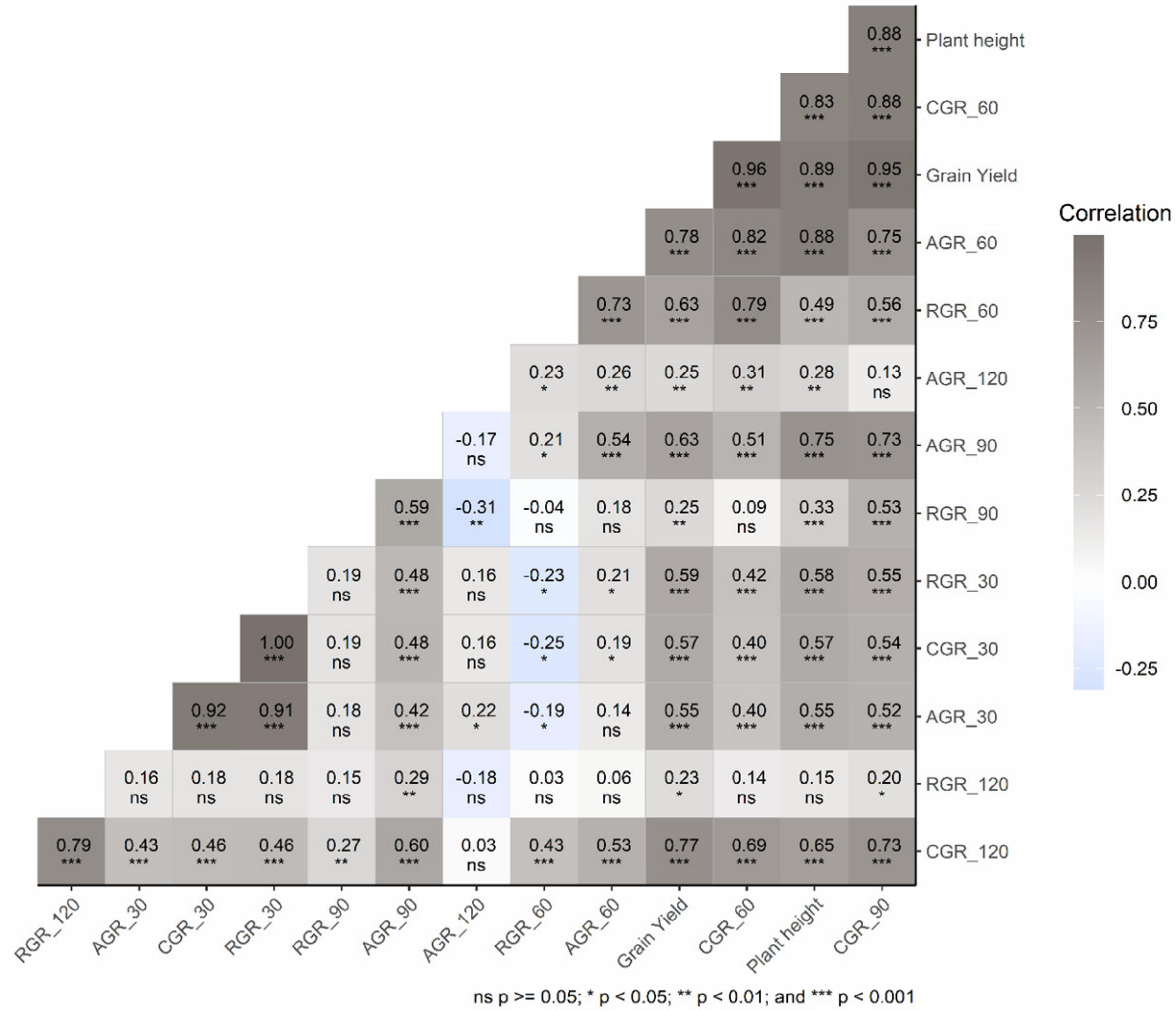

Fig 5: Pearson correlation analysis of different growth indices, plant height with yield of maize (Pooled)

Conclusion

Present study revealed that pre-sown/field operations and herbicides treatments significantly influenced maize growth indices, including plant height, AGR and CGR. Treatments involving glyphosate as a pre herbicide followed by post emergence applications of tembotrione or topramezone resulted in taller plants, highest AGR and improved CGR, similar to weed free conditions. In contrast, flame weeding yielded suboptimal weed control, leading to significantly smaller plants and lower growth indices. A strong correlation was observed between plant height, CGR and yield with the weed control during the critical competition period (30-45 DAS) being crucial for optimal growth. These findings conclude the effectiveness of glyphosate-based treatments for improving maize growth under conservation agriculture.

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