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RESEARCH PAPER

Impact of crop lodging on maize yield parameters, yield and ear abnormalities across diverse tillage practices and nutrient levels

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Abstract Crop lodging pose a significant challenge to maize, especially when strong wind coincides with rains. In the present study we have tested the impact of two tillage systems (conventional tillage with flat sowing and conventional tillage with ridge sowing) and four nutrient levels (50%, 100%, 75% and 150% RDF) on maize crop lodging during *kharif* 2023. Crop lodging was noticed at R2-R3 development stages in maize. The better root system at conservation agriculture nullifies the effect of plant height and plant weight on lodging and therefore root lodging was similar at both the tillage systems. Contrarily, the increased plant height, cob and plant weight under CA + flat planting led to greater incidence of stem lodging (11.7%) as well as total lodging (66.3%) as compared to CT + ridge planting. Root lodging was more severe at both sup-optimal (50 and 75% RDF) and super-optimal (150% RDF) nutrient application, while stem lodging and total lodging were greater at 150% RDF. Among the various nutrient levels, optimal application of nutrients at 100% RDF resulted into least problem of root lodging. Yield losses by root lodged plants were around 50% over standing plants. Stem lodging exhibited 100% yield penalty due to complete stem breakage. Main causes of yield loss were from reduced cob weight, kernel number and cob length. Poor kernel setting at 50% RDF contributed to higher yield loss. Lodging in reproductive stages increased ear abnormalities, vivipary, fungal infection which further reduced grain quality parameters of maize.

Keywords: Abiotic stress • Conservation agriculture • Corn • Crop lodging • Ear abnormality • Flat sowing • Ridge planting

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Introduction

Maize (*Zea mays* L.) is an essential cereal crop, serving as a staple food for millions of people and playing a crucial role in various industries, including livestock feed, biofuel production, and industrial applications (Gul *et al*., 2021). Its adaptability to versatile climatic conditions has imparted to its large-scale cultivation across continents, making it a vital component of food security and agricultural economies worldwide (Bamboriya *et al*., 2024). Globally, maize is being grown over 203.3 m ha area with 1.16 billion ton annual grain production (FAOSTAT, 2022). It is India's third-largest basic food crop that is grown on 9.86 m ha area in India, contributing 31.5 mt produce (DES, 2021). Numerous biotic and abiotic factors impede the yield potential of cereals, with lodging being one of the significant challenges among them (Liang *et al*., 2017).

Extreme weather events, such as heavy rain, strong winds and storms, at or after flowering can increase the likelihood of lodging in cereals by exerting mechanical stress on plants (Bamboriya *et al*., 2024). Lodging is defined as permanent displacement of plant from their vertical position (Acreche and Slafer, 2011). Lodging has two primary forms: stem lodging and root lodging. Stem lodging in maize often results from breakage occurring at or below the cob (Bian *et al*., 2016). On the other hand root lodging occurs when the root fails to anchor sufficiently causes inclination of culms without breakage from the crown. This form of lodging has become increasingly prevalent in cereals, possibly due to the adoption of varieties with shorter and more rigid stems (Bian *et al*., 2016). It is typically associated with the impact of wind-induced forces on the upper portions of the plant (Bamboriya *et al*., 2024). Lodging incurs significant losses in both crop quantity and quality, resulting in harvest challenges, reduced yields, and increased production costs (Liang *et al*., 2017). Agronomic management practices, especially tillage systems and fertilizer application, may alter the risk of lodging by changing the root and stem architecture (Shah *et al*., 2017; Bamboriya *et al*., 2024). Therefore, it is imperative to understand lodging-induced adversities under various tillage and nutrient management scenarios in maize.

Materials and methods

The result presented in this research paper is a part of the long-term experiment initiated from *kharif* 2017 under maize-wheat cropping system at research farm, ICAR-Indian Institute of Maize Research, Ludhiana. The experiment was laid out in split plot design with three replications. The treatments consisted of two tillage systems (conventional tillage with flat sowing and conventional tillage with ridge sowing) in main plot and four nutrient levels (50%, 100%, 75% and 150% RDF) in subplot. Maize hybrid CP 858 was sown on 25th June, 2023 at 67.5 cm row-row spacing using 20 kg seed/ha. Maize rows were oriented in East–West direction. All the recommended package of practices were followed to raise the crop. Plant height, plant and ear weight were recorded from five plants per plot just after crop lodging incidence. Number of root and stem lodged plants were counted from each plot. Per cent root and stem lodging were calculated by dividing their respective plant stand with total plant stand.

Five cobs per plot were collected at harvest to measure cob length (cm), cob diameter (mm), cob weight (g), grains row per cob and grain/cob row. Ear abnormalities in terms of ear stunting, tip emptiness, jumbling (uneven kernel set), vivipary, sunken ear, and ear infection were also measured on a scale of 1–5 where 1 = no ear abnormality and 5 = severely ear abnormality (Nemergut *et al.*, 2021).

Results and discussion

Crop lodging

Strong winds along with rainfall led to crop lodging. Lodging was observed during R2 (blister stage)-R3 (milk stage) stage of maize crop. More than 50% plants were prone to crop lodging. The magnitude of stalk lodging was lower than that of root lodging (Table 1 and Figure 1). Root lodging was non-significant between the two tillage systems. Both, zero tillage with residue retention and ridge sowing under CT had similar favorable impact on root development, therefore the problem of root lodging was similar under both the tillage systems. Better root development with CA (Bian *et al*., 2016) nullified the negative impact of increased plant height, cob weight and plant weight on crop lodging. Therefore, both the tillage treatments had similar impact on root lodging.

Conservation agriculture with flat planting observed slightly higher rate of stalk lodging as well as total lodging over conventionally planted ridge sown maize crop (Table 1 and Figure 1). Plant height and plant weight were significantly higher at conservation agriculture. On the other hand, maize under conservation agriculture had advance crop stage, bigger cob size and greater plant height and plant weight therefore slightly higher crop lodging was observed.

Increase in fertilizer levels increased the problem of stem lodging and total crop lodging due to increased plant height and plant weight. While the problem of root lodging was more prevalent at both low as well as higher fertility levels. Sub-optimal as well as supra-optimal fertilizer application led to poor root growth (Bamboriya, 2024) and poor root anchorage that increased vulnerability towards root lodging. Balance application of fertilizers at 100% RDF (120:60:40) recorded the least root lodging.

Cob parameters and yield

Tillage practices did not have any significant effect on all the cob parameters. Despite the higher crop lodging under conservation agriculture, the magnitude of reduction in yield parameters was statistically similar with conventionally sown maize crop (Table 2). At the time of lodging, crop under CA was at advance stage (R3) than under CT (R2), hence similar yield penalty was recorded between the two tillage systems.

Table 1. Effect of various parameters on crop lodging in maize

Treatment	Crop stage at lodging	Root lodging (%)	Stalk lodging (%)	Total lodging (%)	Plant height (cm)	Plant weight (g)
Tillage						
CA with flat planting	R3	54.5	11.7	66.3	228.9	655.0
CT with ridge planting	R2	47.1	7.3	54.4	214.0	627.5
LSD (p=0.05)	-	ns	3.8	11.1	5.0	ns
Fertilizer level						
50% RDF	R2	51.0	3.9	54.9	211.8	528.3
100% RDF	R3	45.2	12.4	57.6	229.4	688.3
75% RDF	R3	55.2	5.2	60.4	216.7	543.3
150% RDF	R3	52.2	16.3	68.5	228.0	805.0
LSD (p=0.05)	-	6.2	2.4	7.4	10.4	70.0

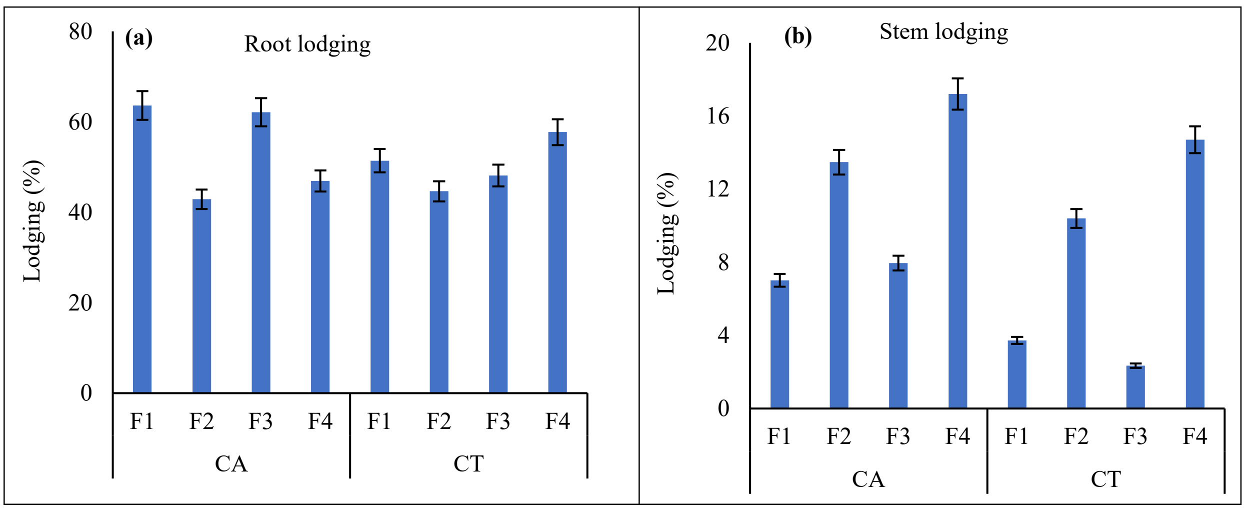

Figure 1. Interaction effect of various treatments on root lodging and stem lodging (b) crop lodging in maize

Cob parameters were significantly affected by fertilizer levels. 150% RDF being at par to 100% RDF recorded the maximum value of cob length, cob diameter, cob weight, grain rows per cob and grains per cob row. Least values of these parameters were obtained with application of 50% RDF.

Data in parenthesis indicate reduction in cob parameters of lodged plants over standing plants. Among the cob parameters, crop lodging severely hampered the cob weight (46.4-56.9%) followed by grains/cob row (29.8-37.1%), cob length (21.0-30.9%) and cob diameter (10.8-15.4%). Crop lodging had minimum impact on grain rows per cob (0.8-6.0%), due to its incidence at late development stage. Interestingly, it was observed that 100% RDF and 150% RDF had least reduction in the cob parameters due to crop lodging. That means higher nutrient uptake in these treatments might have resulted into greater nutrient accumulation and nutrient supply for yield formation.

On an average 50% yield reduction was obtained due to crop lodging at milking stage. Earlier, So *et al.* (2013) also observed 25–40% yield reductions in maize due to crop lodging. Stalk lodging plants had 100% yield reduction as the stem completely broke down due to heavy cob and greater cob placement height. High grain yield penalty at 50% RDF was typically due to incidence of lodging at early development stages (R2). Straw biomass was reduced by 45.1-52.7% in lodged plants due to mobilization of biomass towards grain development. The stalk yield penalty was also higher at 50% RDF suggesting higher biomass trans-location towards grains.

Lodging alters leaf alignment inside the crop canopy, disrupting the light penetration, gas diffusion and microclimate (Lindsey *et al.*, 2021). Besides, crop lodging

Table 2. Effect of crop lodging on cob parameters of maize under various treatments

Treatment	Cob length (cm)	Cob diameter (mm)	Cob weight (g)	Grain rows/ cob	Grains/ row	Yield penalty (%)	
						Grain	Straw
Tillage							
CA with flat planting	12.6 (22.1)	39.0 (13.2)	387.5 (52.0)	14.7 (3.8)	24.2 (31.0)	50.4	52.7
CT with ridge planting	11.6 (27.2)	38.9 (12.8)	366.7 (51.1)	15.3 (4.0)	23.2 (33.6)	49.2	46.1
LSD (p=0.05)	ns	ns	ns	ns	ns	-	-
Fertilizer level							
50% RDF	11.2 (30.9)	37.6 (15.4)	336.7 (56.9)	14.5 (6.0)	22.3 (37.1)	55.7	53.8
100% RDF	12.5 (21.9)	39.3 (11.2)	375 (53.9)	15.4 (2.9)	24.8 (30.1)	48.8	48.5
75% RDF	11.9 (24.7)	38.8 (14.6)	368.3 (49.1)	14.9 (5.9)	23.4 (32.0)	50.9	49.8
150% RDF	12.6 (21.0)	40.0 (10.8)	428.3 (46.4)	15.3 (0.8)	24.2 (29.8)	43.9	44.6
LSD (p=0.05)	0.46	1.56	50.0	0.46	0.99	-	-

Data in parenthesis indicate percent reduction over standing plant.

negatively affect the plant root functions like nutrient and water absorption thus induce premature plant senescence (Liu *et al*., 2012). The combine effect of all these factors led to huge reduction in yield and yield parameters of maize in the study.

Ear abnormalities

Crop lodging cause a large number of ear abnormalities in maize crop (Figure 2). Except vivipary and ear infection, rest other ear abnormalities were not significantly differed

Figure 2. Ear abnormalities in maize due to crop lodging

Table 3. Effect of crop lodging on ear abnormalities under various treatments

Treatment	Ear stunting	Jumbling	Vivipary	Tip emptiness	Sunken ear	Ear infection
Tillage						
CA with flat planting	1.34	0.71	0.29	1.34	0.43	0.35
CT with ridge planting	1.76	0.55	0.10	1.38	0.05	0.13
LSD (p=0.05)	ns	ns	ns	ns	ns	0.20
Fertilizer level						
50% RDF	1.78	0.75	0.10	1.52	0.20	0.20
100% RDF	1.08	0.52	0.18	1.15	0.70	0.13
75% RDF	1.72	0.47	0.07	1.48	0.07	0.03
150% RDF	1.62	0.78	0.43	1.28	0.00	0.60
LSD (p=0.05)	0.52	0.27	0.23	0.25	0.39	ns

between the tillage systems (Table 3). Maize under conservation agriculture recorded higher vivipary as well as ear infection due to greater grain moisture content.

Except ear infection, all other ear abnormalities were significantly differed among the fertilizer levels. Application of 50% RDF recorded the maximum ear stunting and tip emptiness, suggesting poor pollination or kernel set (Ortez *et al*., 2022) due to combined effect of crop lodging and nutrient deficiency. Vivipary was highly noticed at 150% RDF and 100% RDF, because maize in these plots were at R3 stage at the time of lodging. Moreover, the grain moisture content was also higher in this treatment. The severe crop lodging at 150% RDF led ear jumbling. Optimal NPK application at 100% RDF recorded the least root lodging as well as ear abnormalities.

Conclusions

Crop lodging due to strong wind and rain at reproductive stage of maize caused up to 50% yield penalty in lodged plants mainly due to reduced cob weight and kernel number. Vivipary, grain infection and shrunken grains due to lodging further deteriorated the maize grain quality and made it unfit for ultimate user.

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