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ADVERSE IMPACTS OF LODGING AND STRATEGIES FOR MANAGEMENT IN CEREAL CROPS: A COMPREHENSIVE REVIEW

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ABSTRACT

The phenomenon of lodging, which is the collapse of cereal crops as a result of a variety of agronomic and environmental causes, presents serious obstacles to global agricultural productivity. The detrimental effects of lodging on cereal crops are thoroughly examined in this article, including decreased yield, deteriorated quality, increased susceptibility to diseases and challenges during harvest. Numerous lodging management techniques are discussed, including genetic methods, agronomic techniques and technological advancements. The importance of choosing suitable cultivars is emphasised, as well as genetic factors that influence lodging resistance. The effectiveness of agronomic techniques such nitrogen control, planting density optimisation and irrigation timing in reducing the danger of lodging is assessed. Furthermore, the role of technical innovations in lodging prevention is investigated, including enhanced tillage and seed sowing techniques. Through the integration of existing knowledge and research discoveries, this review includes insightful information about the intricate nature of lodging in cereal crops as well as useful suggestions for managing it well to improve the resilience and sustainability of agriculture.

Key words : Lodging, Planting density, Nitrogen management, Technological interventions, Sustainability and Resilience.

Introduction

Lodging is defined as the permanent displacement of a stem (or part of a stem) from a vertical posture. It is often caused by high wind speeds, made worse by wet conditions. External factors like wind, rain, or hail causes grain stalks to be permanently moved from their naturally upright orientation. It is a major global constraint on food production (Baker *et al.*, 1998; Berry *et al.*, 2003; Spink *et al.*, 2003). There are two main types of lodging: stem lodging and root lodging (Berry *et al.*, 2004). Displacement of small-grained cereal shoots from their vertical stance, resulting in permanent leaning or lying horizontally on the ground, can cause a number of secondary effects, including lower grain quality, higher drying costs and a delayed harvest. This can result in yield reductions of up to 80% (Berry *et al.*, 2004). Cereal productivity is impacted by this problem in both industrialised and developing nations. A major obstacle to the development of high-yield cereal crops from seedlings to harvest is lodging. Wind action on the shoot causes stem lodging, but irrigation or rain can weaken the soil, decreasing anchoring strength and causing stems or roots to shift from their upright position (Berry *et al.*, 2004). Reduced yields and lower nutritional density in cereal species and other crops may result from this worldwide. For instance, lodging in wheat makes it more vulnerable to pests and diseases, which hinders crop growth and lowers average grain weight and grain production per square metre (Berry *et al*., 2004). Grain output is still impacted by lodging even if breeding efforts have decreased lodging losses by adding dwarfing genes to reduce plant height (Acreche and Slafer, 2010). Strong-stemmed plants with larger stem bases and stronger walls can be produced by varying the seed rate or applying nitrogen (Crook and Ennos, 1995). Lodging can be affected by a number of variables, including as wind, rain, topography, soil type, preceding crop, management techniques, and disease. Historically, the introduction of semi-dwarf cultivars during the 1960s and 1970s resulted in considerable advancements in lodging resistance. These types generated higher yields due to greater viable florets and grain production per square metre, as well as decreased susceptibility to lodging (Clark and Wilson, 1933; Brady, 1934; Atkins, 1938; Atkins and Ennos, 1938; Heyland, 1956; Vaidya and Malkani, 1963; Pinthus, 1967, 1974; Neenan and Spencer-Smith, 1975; Stanca and Jenkins, 1979). Still, studies on lodging resistance and how it relates to physical characteristics are ongoing.

Lodging in respect to place and time : Accommodation availability varies with the season. Rainfall duration is more closely correlated with lodging than rainfall volume. In winter wheat, root lodging can occur with as little as 4 mm of precipitation. Wind speed was not as important as accommodation. A wind speed that was higher than usual led to lodging. Sterling *et al*. (2003) demonstrated through tunnel experiments that root lodging could occur within 5 minutes when the soil was saturated and the crop was subjected to a mean wind speed of 8 m/s. When grain crops are about ready for harvest, lodging usually increases. As soon as the panicle or ear emerges, lodging may start. According to Easson *et al*. (1993), winter wheat can lodge at any point from the moment its ear emerges until its grains are fully developed.

Detrimental effects of Lodging : Because severe lodging affects grain development and causes harvesting issues and losses, it is exceedingly expensive. Harvesting a lodged crop requires almost twice as much time as a standing one. Harvesting becomes challenging when there is secondary growth along with a flattened crop, which can result in low-quality grain and significant output losses. Lodging often contributes to uneven maturity, high moisture constant and loss of grain quality due to sprouting and possible moulding. Excessive moisture has often delayed harvest and may necessitate grain drying. Lodging can cause severe pickup problems and slow harvest due to green, immature kernels and slowing of the combine speed. All the above can result in increased harvesting costs. Yield losses at this stage will range between 15% and 40%. Lodging that occurs after the plant matures will not affect the yield but it may reduce the amount of harvestable grain. For instance, when lodging occurs after the plant matures, neck breakage and the loss of the whole head can result; these often lead to severe harvest losses. In these cases, farmers who straight combine their grain will likely incur higher losses than those who swath them. Protein content of the grain is generally higher in lodged than standing wheat. The total amount of protein per acre, however, will be less in lodged areas (Laude and Pauli, 1956). Grain qualitycan also be degraded due to lodging by affecting grain size and grain specific weight (Lang *et al*., 2012). Lodging causes bending of cereals to ground, which result in the higher susceptibility of grain to fungal attack (Foulkes *et al*., 2011). Hirano *et al*. (1970) also noted lodging-induced reduction in milling quality in bread wheat.

Lodging negatively affects cereal crops in several ways:

1. **Reduced Yield :** Lodging significantly reduces crop yield by inhibiting photosynthesis, nutrient uptake, and water absorption. When cereal plants lean or lie horizontally on the ground, they compete for sunlight, water, and nutrients, leading to decreased grain formation and overall yield (Berry *et al*., 2004; Acreche and Slafer, 2010).
2. **Decreased Grain Quality :** Lodging often results in poor grain quality, characterized by reduced test weight, increased grain breakage and higher levels of impurities such as dirt, stones and weed seeds. These quality deficiencies lower the market value of the harvested grain and may incur additional costs for cleaning and processing (Baker *et al*., 1998; Berry *et al*., 2003).
3. **Increased Drying Costs :** Lodged crops are more difficult to harvest and dry, resulting in increased drying costs and post-harvest losses. The tangled and unevenly distributed crop canopy impedes airflow and sunlight penetration, prolonging drying times and increasing the risk of mold, mildew and mycotoxin contamination (Spink *et al*., 2003; Berry *et al*., 2004).
4. **Delayed Harvest :** Harvesting lodged crops is slower and more labor-intensive, as machinery must navigate uneven terrain and contend with tangled crop residues. Delayed harvests increase the risk of yield losses due to adverse weather conditions, pest infestations and further deterioration of grain quality (Berry *et al*., 2004; Acreche and Slafer, 2010).
5. **Increased Pest and Disease Susceptibility :** Lodging renders cereal crops more susceptible to

pest and disease infestations, as lodged plants provide shelter and favorable microclimates for pathogens and pests. Increased moisture and reduced airflow in lodged canopies create conditions conducive to fungal diseases and insect damage, further compromising crop health and yield potential (Berry *et al.*, 2004).

6. **Impaired Crop Development :** Lodging disrupts normal crop development and physiological processes, including nutrient translocation, hormone distribution, and reproductive growth. Stems and roots subjected to lodging may undergo structural damage, impairing water and nutrient uptake and stunting overall plant growth and development (Berry *et al.*, 2004; Acreche and Slafer, 2010).

7. **Economic Losses :** The cumulative impact of lodging-related yield losses, quality deficiencies, increased production costs, and reduced market value results in significant economic losses for farmers and stakeholders. These losses undermine agricultural profitability, threaten food security, and hinder rural development efforts in both developed and developing regions (Baker *et al.*, 1998; Spink *et al.*, 2003).

Effects of lodging on cereal yield and quality yield

On Yield : Lodging can reduce cereal yield by reducing the grain size and number or by reducing the amount of crop that can be recovered by the combine harvester. This section deals only with physiological reductions in yield associated with lodging. The greatest lodging-induced reductions in potential grain yield occur when crops are lodged flat at anthesis or early on in grain filling. There have been reports of yield reductions from this kind of lodging: 31% (Weibel and Pendleton, 1964) to 80% (Easson *et al.*, 1993) for wheat, 28–65% (Sisler and Olsen, 1951; Stanca *et al.*, 1979; Jedel and Helm, 1991) for barley and 37% (Pendleton, 1954) for oats. With the exception of (Easson*et al*. 1993), every study mentioned above artificially lodged the plants. This was achieved by growing the plants through wire netting, then moving the wires to effect lodging. This method has the advantage of lodging the crops at specific dates and at different angles, but may induce damage not normally incurred with natural lodging. Easson *et al*. (1993) compared the yields of crops grown at high seed rate, which lodged naturally, with those at low seed rate, which experienced negligible lodging. A number of mechanisms by which lodging reduces the yield of cereals have been postulated. These have been reviewed by Hitaka (1968) and include reduced translocation of mineral nutrients and carbon for grain filling, increased respiration, reduced carbon assimilation within the canopy, rapid chlorosis and greater susceptibility to pests and diseases. The most likely mechanism appears to be reduced carbon assimilation. According to Setter *et al.* (1997), lodging decreased rice productivity by causing neigh boring leaves to shade one another more, which slowed down the pace at which photosynthesis occurred in the canopy. According to this research, the horizontal leaf and panicle layers of the lodged plants' ineffective light interception and use was the primary cause of the limitation. According to a model of light dispersion and photosynthesis in field crops (Monteith, 1965), canopy photosynthesis reduces as leaves become more horizontal for crops with a leaf area greater than five under high irradiance. The reason for this is that although the top leaf layers intercept a greater amount of light, they are either above or close to their light saturation point, making it difficult for them to use it effectively. Partial re-erected crops can occasionally mitigate lodging-induced yield losses, which could be explained by this process of yield loss.

On Quality : The lodging of cereals decrease the harvestable yield either by effects on photosynthesis, e.g. as a result of either poor light penetration in the compressed canopy or stress caused by the damaged conducting system or else by making the grain difficult to harvest. Root lodging significantly alters the number of pores irrespective of soil type, whilst lodging has the most significant impact on pore shape under high density wheat in the clay soil, wherein pore shape changes from rounded to irregular however, there is lesser structural disturbance in pore area in the sandy loam soil as compared to the clay and silty loam soils (Tams *et al.*, 2004). Also, lodging significantly lowered the quality of the cereal. Hagberg Falling Number (HFN) is a metric used to quantify the quality of wheat used to make bread. A ideal HFN of 250s is seen in high-quality wheat. Early or late grain filling lodging considerably lowered the specific weight, 1000 grain weight and HFN. But there was a noticeable rise in the protein content. The low specific weight and tiny grains suggest that lodging decreased the amount of assimilates available to the grains, which in turn raised the protein content. The most typical effect of lodging is a decrease in test weight and shriveling of the grain. Barley's malting quality suffered as a result (Pinthus, 1973). It has also been observed that sprouting in the heads happens more often in lodged crops than in upright ones.

Lodging in relation to stage of occurrence : Pinthus (1973) provided an overview of the yield losses experienced by various grains at various phases. At

Fig. 1 : Effect of lodging in wheat crop after heavy rain followed by wind.

heading, there were higher yield declines (27–40%) than 15-20 days later (1739%). Irrespective of the crops and locales, the decreases were highest at the heading stage. When barely cultivars are stuck during the milk stage, their yields are reported to be reduced (Jedel and Helm, 1991). The amount of lodging also varies according on the cultivar; Samson, a barley variety, recorded 19–28%, while Johnston recorded 22–40%.

Causes of lodging : Lodging, the phenomenon where cereal crops lean, bend, or collapse, significantly impacts agricultural productivity worldwide. It occurs due to a complex interplay of environmental, soil, genetic, and management factors. Understanding the causes of lodging is essential for developing effective management strategies to mitigate its detrimental effects and enhance crop resilience. The causes of lodging encompass a range of factors, including environmental stressors such as wind and rainfall, soil characteristics such as texture and nutrient availability, crop management practices such as planting density and fertilization, genetic traits related to stem strength, pest and disease pressure. Each of these factors contributes to the susceptibility of cereal crops to lodging, highlighting the multifaceted nature of this agricultural challenge. In this discussion, we will explore the various causes of lodging in detail, drawing upon scientific research and reviews to elucidate the complex mechanisms underlying this phenomenon. By understanding the underlying causes of lodging, researchers, agronomists and farmers can develop targeted strategies to minimize its occurrence and maximize crop yield and quality.

Environmental Factors

(i) Wind : Strong winds exert mechanical forces on cereal crops, causing them to bend or break. Wind speed and direction, as well as the duration of windy periods, contribute to lodging susceptibility (Spink *et al.*, 2003; Baker *et al.*, 1998).

(ii) Rainfall and Irrigation : Excessive rainfall or irrigation can saturate the soil, reducing its stability and anchorage strength. Waterlogged soil increases lodging risk by weakening root systems and compromising plant stability (Berry *et al.*, 2003; Acreche and Slafer, 2010).

(iii) Topography : Sloping terrain or uneven ground surfaces can amplify lodging susceptibility, as plants on steeper slopes are more prone to being uprooted or bent by gravitational forces (Spink *et al.*, 2003).

Soil Factors

(i) Soil Type : Soil texture, structure, and compaction affect root anchorage and soil stability. Sandy soils provide poor anchorage compared to loamy or clayey soils, increasing lodging risk, particularly during windy or wet conditions (Berry *et al.*, 2003; Spink *et al.*, 2003).

(ii) Nutrient Availability : Imbalances in soil nutrients, particularly nitrogen, phosphorus, and potassium, can influence lodging susceptibility. Excessive nitrogen application, for example, promotes vegetative growth at the expense of stem strength, increasing lodging risk (Acreche and Slafer, 2010; Spink *et al.*, 2003).

Crop Management Practices

(i) Plant Density : High plant populations can exacerbate lodging risk by intensifying competition for resources such as sunlight, water and nutrients. Dense stands promote elongated, weak stems that are more susceptible to bending or breaking (Berry *et al.*, 2003; Spink *et al.*, 2003).

(ii) Fertilization : Imbalanced or excessive fertilizer application, particularly nitrogen, can lead to excessive vegetative growth and weak stems. Proper nutrient management is essential to maintain a balance between vegetative and reproductive growth and minimize lodging risk (Acreche and Slafer, 2010;

Baker *et al*., 1998).

(iii) Plant Height : Tall, erect varieties are more prone to lodging than shorter, semi-dwarf varieties. Breeding efforts have focused on developing semi-dwarf cultivars with improved lodging resistance by reducing stem length and increasing stem strength (Berry *et al*., 2003; Acreche and Slafer, 2010).

Genetic Factors

(i) Stem Strength : Genetic traits related to stem strength, including stem diameter, lignin content, and cell wall thickness, influence lodging resistance. Breeding programs aim to incorporate genes associated with strong, stiff stems to enhance lodging resistance (Berry *et al*., 2003; Acreche and Slafer, 2010).

Disease and Pest Pressure

(i) Fungal Diseases : Pathogens such as *Fusarium* spp., *Rhizoctonia* spp., and *Pythium* spp. can infect cereal crops, weakening stems and increasing lodging susceptibility. Fungal infections compromise stem integrity and reduce lodging resistance (Berry *et al*., 2003; Spink *et al*., 2003).

(ii) Insect Pests : Insect infestations, particularly stem borers and aphids, can weaken stems and increase lodging risk. Pests damage vascular tissues, impair nutrient uptake, and compromise plant health, leading to lodging (Acreche and Slafer, 2010; Berry *et al*., 2003).

Mechanics of lodging

Lodging is induced by high speed winds and the forces exerted on the plants can lead to structural failure, either the uprooting of whole plants or else the breaking or buckling of stems. This process of plants being laid flat by the wind is called lodging. The commonest form of lodging in wheat is buckling of the stem. In wheat, barley and oats, stem lodging is usually caused by one of the bottom two internodes buckling which results in the upper stem and ear lying horizontally (Mulder, 1954; Neenan and Spencer-Smith, 1975). The occurrence of lodging depends on the forces exerted on the plant by wind, rain, etc., on the height from the ground at which they act, and on the strength of the stem (Grace, 1977 and Niklas, 1992).

Management options to reduce lodging

Various factors affect lodging significantly. Environmental factors like temperature, rainfall (water/ irrigation), wind velocity and light affect the lodging. Nitrogen application has higher significance, while potassium, seeding rate and seeding time had moderate effect on the lodging.

1. **Genetic improvement :** During the last century, genetic gain in wheat yield ranged annually from 0.3% to 1.0% (Graybosch and Peterson, 2010), which is true for Indian conditions as well (Gupta *et al.*, 2017). Genetic gain has largely been attributed to reduced plant height with better allocation of assimilate toward sink resulting in significantly improved harvest index (HI) (Foulkes *et al*., 2010). Further improvement in HI is very hard to come as modern cultivars are very close to theoretical limits of 0.62 (Álvaro *et al*., 2008 a,b; Austin *et al*., 1980). Increased biomass with inbuilt lodging tolerance advocated as a mean of achieving a breakthrough (Sadras and Lawson, 2011; Sanchez-Garcia *et al*., 2013). Plant height has been the most discussed character positively correlated with lodging. Introduction and adoption of the dwarfing genes (*Rht1* and *Rht2*) containing varieties Lerma Rojo and Sonara 64 from CIMMYT, Mexico in 1960's led to quantum jump in the developing world especially Indian subcontinent led to green revolution. The lodging was drastically reduced due to reduced height and response to fertilizers and irrigation was realized. Following which most of the Indian varieties released after 1960s contain these two genes only (Jain, 1994). Use of *Rht* genes led to design high yielding and fertilizer responsive genotypes, which rule largest area of spring wheat in world .

2. **Agronomical practices :** The agronomic factors are perhaps most studied and reported factors related to lodging in wheat. Sterling *et al.* (2003) observed that the risk of lodging is strongly influenced by a number of husbandry decisions including variety choice, sowing date, drilling depth, soil fertility and the application of plant growth regulating chemicals. Their influence on lodging risk has been shown to be through their ability to alter crop structure by affecting certain plant characteristics. There are reports that use of N-fertilizer in pockets of Punjab and Haryana is much higher than the required dose as per recommendation by research organization. Overdose of nitrogen induces the succulence in plants making them prone to lodging and disease attack (Tripathi *et al*., 2002). One of the factors is timing and intensity of irrigation and use of N-fertilizer. The time of application of nitrogen has effect on lodging. Low nitrogen at the time of sowing has been reported to significantly reduce lodging in spring wheat while maintaining the same amount of total nitrogen applied (Peake *et al*., 2016). It is standard practice in northern India to irrigate the fields by flooding method

and in majority of cases the fields are over flooded giving more windows to environmental factors to induce lodging. This is mainly done due to timing of electricity supply in rural area.

(i) Spring Wheat Lodging : Hull (1967) observed increased lodging in spring wheat planted on ploughed land compared to slit seeding into unplowed grass sward. This suggests that reduced tillage methods may mitigate lodging in spring wheat.

(ii) Barley Lodging : Subsoiling was found to increase lodging in barley compared to a regularly prepared seed bed, while rolling after sowing decreased lodging (Hull, 1967).

(iii) Maize Lodging : Tillage did not significantly affect lodging in corn. However, yield improvement was noted under conventional tillage (Pedersen and Lauer, 2002).

(iv) Tillage and Nitrogen Interaction in Wheat : Tillage practices interacted with nitrogen application rates to influence lodging in wheat. Higher nitrogen rates combined with tillage resulted in lodging effects (Pedersen and Lauer, 2002).

(v) Nutrition's : Increasing nitrogen supply to cereals increased the length of the bottom internodes, but actually shortened the upper internodes, to effect a relatively small reduction in overall height. It therefore seems unlikely that an increase in height is the main cause of lodging in response to more nitrogen. Hence supply of optimum dose of N, helps to reduced lodging losses. The effects of potassium, phosphorus and trace elements are less pronounced than that of nitrogen. Moderate application of phosphorus and potassium it reduction in lodging.

(vi) Crop rotation : Crop rotation is necessary for the prevention of diseases such as common root-rot, scald, net blotch, and root rot and take-all. When a cereal crop is grown on broad leaf crop, such as canola or flax, the less severe is the disease pressure. Crop rotation practices can be particularly important for irrigation farmers. In the absence of summer fallowing, a crop rotation scheme is useful for the maintenance of soil fertility, disease and weed control. In addition, careful rotations can aid in lowering protein levels in soft white spring wheat and malt barley.

Impact of Planting on Raised Beds : Planting on raised beds emerges as an effective strategy to control lodging in wheat. Srivastava et al. (2003) highlighted that lodging-prone wheat cultivars with high yield potential can be grown on raised beds to enhance yields. Notably, the lodging-susceptible wheat cultivar Pastor exhibited a substantial reduction in lodging under bed planting conditions (Sayre and Hobbs, 1998). However, it's noteworthy that bed planting may not be universally suitable for all cultivars, and it was observed to reduce wheat plant height while significantly improving grain yields.

Utilization of Improved Seed Planters in Rice : In Japan, the adoption of improved seed planters, such as the hill seeder, has shown promise in reducing lodging in rice. The hill seeder facilitates grouping of rice seeds, mimicking hill-transplanted rice, thereby enhancing plant strength and resistance to lodging. This innovation resulted in decreased lodging index and lodging degree, as demonstrated by Satoshi (2005).

Effect of Crop Rotation on Lodging : Continuous cultivation of corn in rotation resulted in fewer broken plants compared to corn-soybean rotation, where higher broken plant percentages were observed. Pioneer hybrid 3162 exhibited minimal lodging under both Corn-Corn and Corn-Soybean rotations, while other hybrids experienced severe lodging under corn-soybean rotation. Consistent observations were reported by Pedersen and Lauer (2002).

1. **Growth regulators :** Plant growth regulators (PGRs) have been recommended for reducing the height, stiffen straw, and reduce lodging. However the efficacies of such hormones have been giving differential results and there is differential response of genotypes (Berry *et al.*, 2004). The use of growth regulators seems akin to use of dwarfing genes but in case if countries like India any extra recommendation to use growth regulators in addition to fertilizers and weedicides will not be very viable choice as considering very large acreage under crop will lead to substantiated input cost which otherwise can be managed by giving the better genotypes to withstand lodging.
2. **Diseases management :** It is a known fact that diseased plants are more prone to lodging and vice versa. Therefore the inbuilt resistance of important diseases of wheat according to their prevalence in a zone/area is a prerequisite step before the release of varieties in India. The disease resistance is strictly followed by breeders and monitored by the strong coordinated program of wheat improvement which is one of the best in its kind in world. The occurrence of outbreak of disease due to bust phase of cycle of resistance in more prominent varieties needs to be

tackled with the second line of precaution that is use of chemicals for immediate relief followed by phasing out the variety.

3. **Irrigation :** Reducing the lodging occurs when excessive vegetative growth is restrained by postponing or forgoing first watering. This suggests that postponing or forgoing the initial watering may reduce lodging. The lodging in wheat decreased from 60% to 10.1% by delaying the initial watering from 20 DAS to 40 DAS. But in Uttar Pradesh, India's Tarai climate, providing irrigation at 30 DAS is proven to be ideal for lower lodging and higher wheat yields (Pandey *et al*., 1995). The root system's ability to attach itself is weakened by excess moisture in the top soil layer. Conversely, the top layer's dryness may inhibit the coronal root system's growth and encourage lodging. In dry situations, lodging on clay soils might result from soil cracking that harms the roots (Hurd, 1964).
4. **Nitrogen :** Elevated nitrogen levels cause plants to grow higher, which enhances lodging. The range of the rise is 2.3% to 10%. Lower internode length rose and higher internode length decreased with increasing nitrogen. According to Hobbs *et al*. (1998), heavy nitrogen weakened the stem wall breadth, stem diameter, and anchoring system. Lower internode elongation is only caused by self-shading. Regardless of the soil's nitrogen level, the full application of nitrogen during planting caused lodging. It is best to apply at the beginning of irrigation or early booting to have a reduced lodging percentage. Increased nitrogen may also cause limitations in coronal root growth. It was discovered that the application of high N rates had impaired the root anchoring of a semi-dwarf wheat variety. Since it generally has a greater influence on shoot development than on root growth, more N supply will always lead to a higher shoot:root ratio, which is favorable for lodging (Pinthus, 1973).
5. **Clipping and Grazing :** Clipping or grazing can be used to control excess foliage during the lower culm internodes' elongation stage. This needs to be completed prior to adequate culm elongation. This approach is effective in reducing lodging and in some circumstances, it also increased grain output. But majority of the time, after grazing or chipping, grain output decreased. Although, the yields were decreased, this strategy is helpful in lowering lodging.

Conclusion

Lodging in cereal crops remains a persistent challenge with significant implications for agricultural productivity and sustainability. This comprehensive review has highlighted the adverse impacts of lodging, including reduced yield, quality deterioration, increased susceptibility to diseases and harvesting difficulties. However, through the exploration of various management strategies, including genetic selection, agronomic practices and technological interventions, promising avenues for mitigating lodging risk have been identified. Genetic approaches offer the potential to develop lodging-resistant cultivars tailored to specific environmental conditions and cropping systems. Selecting cultivars with traits such as shorter stature, stronger stems and improved root anchorage can enhance lodging resistance. Furthermore, advances in molecular genetics hold promise for accelerating the breeding of lodging-resistant varieties. Agronomic practices play a crucial role in lodging management, with optimal planting density, balanced nutrient management and appropriate irrigation scheduling being key considerations. Implementing practices such as reduced nitrogen application rates, strategic irrigation timing, and proper seedbed preparation can help minimize lodging incidence and severity. Technological interventions, including improved tillage methods, precision seed planting techniques and the use of growth regulators, offer additional opportunities for lodging prevention. Adopting raised bed planting, subsoiling and employing advanced seed planters can contribute to enhancing crop anchorage and reducing lodging risk. In conclusion, addressing lodging in cereal crops requires a multifaceted approach that integrates genetic, agronomic and technological strategies. By implementing a combination of these management practices, farmers can effectively mitigate lodging risk, improve crop resilience and enhance overall agricultural productivity and sustainability in cereal cropping systems. Continued research and innovation in lodging management are essential to address this critical challenge and ensure food security for future generations.

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