

MANAGEMENT AND MANURIAL ASPECTS OF CROP LODGING

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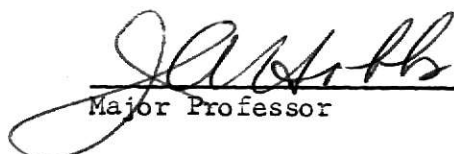
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INTRODUCTION

Crop lodging is one of the major hazards that may accompany attempts to increase yields by application of heavy doses of fertilizers. Soil management systems which are conducive to high yields are also associated with crop lodging. Lodging has been recognized as a source of great loss, especially when the level of soil fertility is high.

Lodging may be brought about because of the unusual susceptibility of the particular crop or because of severe external forces such as strong winds and heavy rains. Accurate evaluation of the resistance of various varieties of grain crops to lodging is very difficult, as the abundance of rainfall and the occurrence of relatively high temperature, weather conditions which are associated with the production of weak stems, vary considerably from season to season. In addition, the growth stage of the crop at which it is subjected to lodging determines the actual amount of lodging and the amount of loss and damage. The loss is of greater magnitude when it is imposed at heading stage than at any other stage thereafter.

Weibel and Pendleton (1964) observed that reduction in yields in cereal crops due to lodging was as follows: at heading 31 percent, at milk stage 25 percent, at soft dough stage 12 percent, and at hard dough stage 20 percent.

The problem of lodging has already received considerable attention because of the immediate economic loss involved and because of the great limitations it imposes on further boosting of grain yields. Investigations have been conducted by numerous workers probing into environmental, morphological, cytological, physical and chemical factors, in an attempt to

learn the reasons for lodging. Today it is accepted that lodging is not the result of any single factor but is affected by a complex of different factors.

REVIEW OF LITERATURE

Morphological Characters and Lodging

Lodged plants differ morphologically from nonlodged ones in weight and length of culms. These changes have been attributed to the effects of environmental, soil, managerial and manurial conditions during the growth period. Therefore, the study on the process of elongation of the stem, and the changes in dry weight of certain parts such as leaf-blade, leaf-sheath internodes and panicles, attracted the attention of many research workers.

Relationships between lodging resistance and certain culm characters studied by Jellum (1962) revealed that oat varieties that resist lodging had larger stem diameters and thicker culm walls than susceptible ones. Increased plant density reduced stem diameter, vascular bundle number, culm wall thickness, pith cavity, and diameter and width of the sclerenchyma layer. Bezdek (1964), while studying the morphological characters of two barley varieties, Valticky, and Domin, observed the following characters responsible for lodging:

- (1) Increased weight of organs above ground, particularly of leaves.
- (2) Increased tillering (density of the stand).
- (3) Prolonged length of basal internodes.
- (4) Decreased accumulation of any substance of internodes, blades and sheaths.
- (5) Raised level of nitrogen and phosphorus in some parts of the plants.
- (6) Decreased content of total sugars.

Hitaka and Kobayashi (1962) in their study on lodging of rice plants

showed that bending of rice culm at the milk stage reduced uptake of nutrients and water. The effect appeared to be proportional to the severity of bending. No uptake occurred when the culm was cracked, although uptake resumed when the cracked culm was held upright. It was calculated that loss of yield in lodged rice is due to reduced translocation in the culm and to shading experienced by the panicle.

Studies conducted by Sechler (1961) on root development and lodging resistance in oats revealed that lodging was positively related to the length of the root crown, diameter of the culm (2.5 cm above ground) and diameter of the coronal roots (at emergence from the crown) and inversely related to the (dry weight) ratio of top growth to roots. Deep sowing, as compared to shallow, increased the length of the root crown but reduced the seedling vigor. Therefore, he suggested that potentially long crowned varieties should be sown deep to exploit this factor.

In West Bengal (India) Basak, Sen and Bhattacharjee (1962) reported some important morphological differences between lodged and nonlodged plants. They observed that lodged plants had a higher straw/grain ratio, lower specific gravity of the culm, and lower percent crude fiber and silica content than normal plants. Holmes (1960) studied the influence of periodic shading on the length and solidness of the internodes of 'Rescue' wheat. Plants were shaded during (a) emergence to 2 leaf stage, (b) 2 leaf to 4 leaf stage, (c) 4 leaf to boot stage, (d) seedling emergence to boot stage, (e) boot stage to earing. He observed that treatment (b) decreased the length of the lowest 4 internodes, treatment (c) increased the length of the first three internodes and decreased that of the 4th and 5th internode, treatment (d) increased the length of the 2nd internode and decreased that

of internodes 3, 4 and 5 while treatment (e) increased the length of internode 4 and decreased that of internode 5. Thus shading during the initiation of elongation of an internode reduced its final length, while shading during later stages of elongation caused the internode to elongate as much as or more than if the plant had remained unshaded. The shading treatments tended to cause the lower 3 internodes to become hollow. Treatment (e) alone caused severe lodging.

Jellum (1961) in his experiments on histological and morphological study of certain culm characteristics in relation to lodging of ten oat varieties concluded that morphological factors such as type of root system, stem diameter and plant height influenced lodging resistance to a greater extent than did internal histological structure. Wheat plants with low lignin and cellulose content and with tendency toward sheath base elongation were found by Johnson (1961) to be susceptible to node bending type of lodging. He observed that cool wet weather at the end of the vegetative period and wet weather with strong winds at maturity are mainly responsible for the node bending type of lodging.

Phillips, Davidson, and Weihe (1931) in their studies of lignin in wheat straw with reference to lodging observed that in all cases where lodging had occurred plants contained a higher percentage of methoxyl and lignin than did the stalks from the plots where no lodging had taken place. The cellulose content was also greater, except in the last stages of growth, in the stalks from the plots where the plants lodged than in the plots where the plants did not lodge. In the early stages of growth the ash content was higher in the stalks from the lodged plants than in those from the non-lodged; but in the later stages the relation was reversed. A significant

decrease in silica content was observed in lodged plants. Welton (1928), from his extensive studies on lodging in oats and wheat, suggested a number of morphological and physiological factors responsible for lodging. According to him lodging results from low dry matter per unit length of culm. Low dry matter per unit length of culm may result from a relatively low composition of lignin and various residue materials, such as disaccharides and polysaccharides, or from the development of relatively small slender culms. Culms small in diameter but medium or high in composition of carbohydrates may result from direct causes such as thick seeding or planting of small seeds. Culms low in carbohydrates are due to development within the plant of a low carbohydrate:nitrogen relation. A low C/N ratio may result from hypernutrition, shading, or relatively high temperature. Hypernutrition not only tends to induce the greatest elongation of culm, but, through a stimulation of tillering processes, it increases the thickness of stand and hence results in a greater degree of shading around the base of the plants. In warm, rainy, cloudy seasons the conditions are most favorable for the development of lodging in rich soils.

The average number of culms was greater in the lodged than in the erect oats in each of the five years tested; the difference ranging from 16 to 74 percent. His findings are presented in Table 1.

Lodging is dependent on a number of factors which vary greatly from year to year, thus making it difficult to find out one index of lodging that may be considered completely reliable. However, research was carried out by various workers to find some reliable methods through which lodging can be expressed.

At Kansas Agricultural Experiment Station, Miller and Anderson (1963)

Table 1.--Number of culms per square meter in erect and lodged oats (Welton, 1928).

1920 Ohio 6222		1921 Ohio 201		1922 Ohio 201		1923 Ohio 201		1924 Ohio 201	
E.	L.	E.	L.	E.	L.	E.	L.	E.	L.
291	376	234	241	178	199	236	242	247	293
311	400	141	266	220	202	230	219	202	313
313	352	194	238	227	262	191	240	184	265
299	364	172	242	214	260	241	254	196	286
287	353	171	235	245	253	233	236	191	254
300	375	170	342	182	238	224	251	177	275
282	345	247	195	212	249	220	255	175	312
297	347	198	215	191	217	260	234	155	295
344	351	204	259	223	248	249	293	149	313
298	362	223	271	218	252	242	262	195	303
Averages									
303	359	195	251	211	238	233	254	188	292

conducted studies on 8 varieties of wheat over a period of 2 years, both in the glass house and field. They developed the following numerical expression for measuring the resistance of plants to lodging.

$$R = LBC/(\text{Log plant height}/3)^2$$

where R = resistance

LBC = Load bearing capacity

Atkins (1938) reported a positive and significant correlation coefficient for lodging and length of lower internode and for lodging and date of maturity in one season of the three in which these relations were studied.

Studies of oat varieties carried out by Davis and Stanton (1932) revealed a significant correlation between the breaking strength of straw and several plant characters such as weight of panicles, weight of grain, weight of straws broken, height of culm and width of second leaf. A correlation

coefficient of $+0.863 \pm 0.30$ was obtained between the breaking strength of straw and weight of straws broken of 32 improved registered varieties for the years 1929 and 1930. Wilson (1930), in his studies on plant characters as indices of the ability of corn strains to withstand lodging, indicated that the distance between the lower internodes and the accompanying development of brace roots may be useful in predicting the probable resistance to lodging under field conditions. In Japan, Siko (1962) carried out an intensive study on factors causing lodging. He suggested the following formula by which the liability of crops to lodging could be measured with the index of lodging. It was reported when the index of lodging at the lower internodes (distance between fulcra is 5 mm) rises above 200, the plant is liable to lodge.

			1-1-1. Height of culm	
		1-1. Height of plants	1-1-2. Height of centre of activity of culms	
		1-2. Weight of plants	1-2-1. Weight of culms	
Index of	1. Bending		1-2-2. Area of load surface	
lodging=	<u>moment</u>			
	2. Breaking strength			
		2-1. Length of lower internodes	2-2-1. Cross sectional area of culms	
		2-2. Strength of culms	2-2-2-1. Mechanical tissue	Chemical
			2-2-2. Qualities of culms (Strength of leaf-sheath is added secondarily)	compo- nents
			2-2-2-2. Turgor	

The investigation carried out by Spahr (1960) on rigidity in spring barley revealed that the most important factor in resistance to lodging was the cellulose content of the lower two-thirds of the stem. In nonlodging varieties this value was high at flowering (the critical stage of lodging).

Grafius and Brown (1954) tried to express the factor lodging through a suitable formula. To improve the accuracy of their findings, they proposed three hypothetical types of bending of an oat culm. Bending at the base (root lodging), bending uniformly throughout, and bending mainly at the top (buggy whip type). It was shown that in the act of lodging the panicle base would generate an ellipse of the form

$$x^r = a^r (1 - z^r y b^r)$$

a = Length of the horizontal axis

b = Height of the plant to panicle base

x and y = cartesian coordinates for the positive of the panicle base at a given instant. They also found that the crop lodging resistance (CLr) factor had good repeatability, $r = 0.73$. It was found to give a highly significant correlation with lodging $r = -0.48$. Finally they defined lodging as the extent of response to torque caused by external forces, lodging resistance as the ratio of the additional torque (over and above the weight of culm leaves and head) a culm is capable of resisting (T_r) to the torque (T_a) applied by external forces such as wind and rain, and the stiffness of the culm as the torque required to move the base of the head from y to y_E where E is relatively small when compared to b and x approaches v .

Crop Losses Due to Lodging

Crop lodging is found to affect materially both the quality and

quantity of grain. The magnitude of loss depends largely upon the completeness of falling of the crop and the state of development at which it occurs. The subsequent weather conditions also decide the losses that take place. Studies were conducted from time to time to assess correctly the crop losses under different conditions and stages of crop lodging.

Laude and Pauli (1956) in their studies on influence of lodging on yield and other characters in winter wheat observed that yields were reduced about one-third due to lodging 1 to 2 weeks before heading and 1 to 2 weeks after heading. Lodging between these periods caused less reduction averaging about 15 percent just before heading. Early lodging mainly reduced the number of kernels per head and later lodging reduced the size of the kernel. Their results are presented in Figure 1 and Table 2.

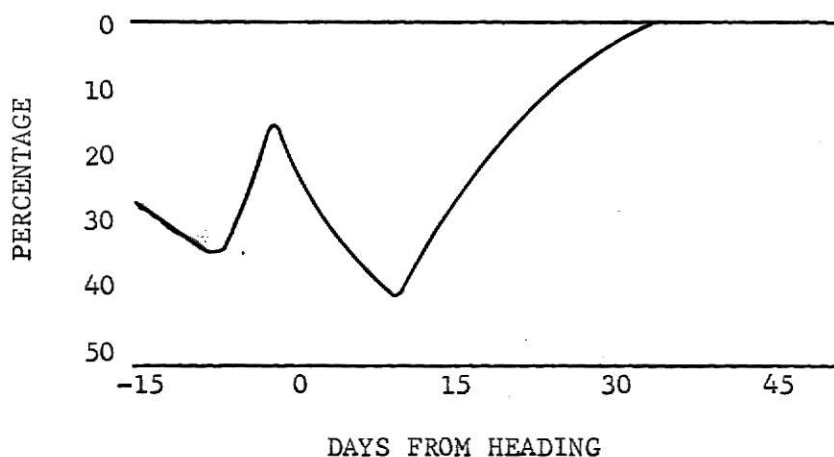


Fig. 1.--Percentage decrease in acre yield of wheat caused by manual lodging.

Weibel and Pendleton (1964) observed that reduction in yields due to lodging at heading stage was 31 percent, milk stage 25 percent, soft dough stage 12 percent, and hard dough stage 20 percent.

Table 2.--Effect of manual lodging of winter wheat at different stages on acre yield, number of kernels per head, weight of kernels, and bushel weight (Laude and Pauli, 1956).

Time lodged, days from heading	Percentage decrease of lodged compared with undamaged wheat 1949-1954			
	Acre yield	Number of kernels per head	Kernel weight	Bushel weight
	%	%	%	%
-11 to -15	31.4	22.8	17.3	5.6
-6 to -10	33.7	13.6	5.5	5.5
-1 to -5	16.3	12.1	7.1	2.7
Heading 0 to 5	27.3	17.2	11.4	6.1
6 to 10	35.2	22.8	16.0	8.0
11 to 15	37.0	20.6	22.7	11.0
16 to 20	21.7	5.6	17.0	8.1
21 to 25	16.0	6.1	14.1	6.4
26 to 30	7.5	1.2	6.6	3.0
31 to 35	7.8	0	7.1	3.9
36 to 40	2.2	0	1.8	1.1
L.S.D. at 5% level	3.9	4.3	3.0	1.0

Crop Lodging as Related to Crop Management

Improper crop management practices such as heavy seeding rate, wrong sowing season, defective irrigation and defective tillage practice, can be some of the important causes of crop lodging. Attempts have been made by several research workers to study the effects of various crop management practices on crop lodging.

At Florida Agricultural Experimental Station, Norden (1966) conducted research work on the effect of varying plant densities on the yield, plant height and lodging of corn on a poorly drained sandy soil. A positive curvilinear relationship was observed between plant population and yield per acre and a negative linear relationship between plant population and yield per plant. Raising the population from 12,350 to 61,750 plants per hectare decreased the grain yield per plant by 73 percent, while plant height was increased by 5 percent and lodging increased by 17 percent. Increased lodging at higher plant population was reported to be the result of reduction in root density, without an accompanying reduction in plant height. His results are presented in Table 3. Investigation of Taltersfield (1959) revealed that increasing row spacing of wheat from 17.5 to 35.0 or 52.5 cm lowered grain yield per hectare and increased the incidence of lodging. Hoff and Mederski (1960) reported that percentage of lodged plants tended to increase with increasing stand density but was independent of the method of sowing. Mishra et al. (1963) in their investigation of high population corn for forage and green manure, noted that increased lodging accompanied higher population of crops. Long (1961) from the results of the spacing trials conducted on maize suggested that the plant density must be adjusted to the productive level of the field to prevent lodging. He recommended as a general rule to allow 247 plants to each bushel of grain expected per hectare. In most instances 29,640 to 37,050 plants/hectare were found to be optimum and further increase in number often resulted with increased lodging. Nelson (1960) reported that lodging resistance of three varieties of irrigated spring wheat was reduced with increasing population.

The method of sowing is found by many workers to influence lodging in

Table 3.--Effect of plant population and season on the yield, plant height, and lodging of corn on poorly drained sandy soil (Norden, 1966).

Plants per hectare	Yield of grain						Plant height,			% plants lodged, mean
	Quintals/hectare			g/plant			cm			
	1960	1961	mean	1960	1961	mean	1960	1961	mean	
12,350	46.3	34.0	40.1	375	292	334	266.7	220.9	243.8	2
24,700	59.4	43.7	51.6	241	177	209	274.4	238.8	265.5	4
37,050	59.3	46.9	53.1	160	127	144	281.9	233.7	259.1	9
49,400	61.0	52.1	56.6	124	106	115	281.9	233.7	256.5	11
61,750	60.9	47.4	54.2	99	77	88	281.9	231.1	256.5	19
Mean	57.3	44.8	51.1	200	156	178	276.9	231.1	254.0	9
L.S.D. (P=0.05)										
	4.1	7.2	3.7	21	27	18	4	5	3	5

cereal crops. Castillo (1962) conducted a comparative study of directly seeded and transplanted crops of rice with reference to lodging. Three varieties of rice, Milfer 6(2), B-436, and Peta (respectively resistant to lodging, intermediate and somewhat susceptible to lodging) were established by (a) direct sowing of germinated seed and (b) transplanting. Plants from (b) were taller, later in heading and had lower panicles than those from (a). Peta gave consistently higher yields under (b), Milfor 6(2) gave higher yields under (a). Thus direct sowing appeared to be suitable for the low tillering, nonlodging variety while transplanting appeared to favor the high tillering, lodging variety. Narahari and Pawar (1961) conducted a study that compared lodging from broadcast sprouted seed and from dibbling in soaked and sprouted rice seed at Rajendranagar, Andhra Pradesh, India.

The dibbled seed was sown at 4 to 5 seeds per stand arranged at 20 x 20 cm. They reported that the broadcast crop lodged 7 to 10 days earlier than the dibbled crop. There was a significant increase in yield in the dibbled crop. Bunting and Willey (1959) reported that several tall, late varieties of maize which they studied tended to produce more dry matter at low plant densities than did earlier varieties. A greater percentage of lodging and of infertile ears occurred at high plant densities.

Preliminary investigations conducted by Kempanna (1960) on the effect of different dates of sowing of paddy on some of the yield contributory characters revealed that the plants sown in June were the tallest and had the highest number of spikelets and of grains per ear, but they lodged badly.

Abel (1961) studied response of soybeans to dates of planting in the Imperial Valley of California. When five varieties of soybean of varying maturation periods were sown at fortnightly intervals from May 2 to August 2, delay in sowing was largely offset by the contraction of the period to maturity. This contraction occurred after flowering in the earliest and before flowering in the latest maturity variety. The highest yields of seed were obtained from intermediate and medium late varieties sown in May and June. Delayed sowing reduced plant height in tall varieties especially but there was less lodging as a result. Seed quality improved with delayed sowing but seed size diminished in the last three sowings, particularly in the earlier varieties.

Standing ability and yield of six varieties of oats, when grown alone and as equal mixtures of any two varieties, were compared for four years by Patterson et al. (1963) to test the hypothesis that blends of two varieties,

differing in maturity, would be less subject to lodging during storms. Theoretical support for this hypothesis is that usually no more than 50 percent of the plants would be in the most susceptible stage for lodging at any given time. Furthermore the variety in a susceptible stage would receive some support from the second variety. They reported less lodging in the mixtures in the first year of valid comparison but in general yields of mixtures did not differ from those obtained when the two varieties were grown separately.

The time of irrigation and the type of irrigation has been found to influence lodging in crops. Experiments conducted by Siko (1958) showed that deep water irrigation or drainage (respectively) decreased or increased resistance to lodging in rice if certain internodes (N4 and N3) were undergoing elongation at the time of treatment. The production of mechanical tissue of the internodes was found to have been influenced by deep water irrigation or drainage. Lang and Shu (1960) reported that drying of the field at late tillering stage decreased lodging and promoted root respiration and prevented ineffective tillering.

An experiment was conducted by Garderner and Wiggins (1960) for three seasons using No. 0-205, a high tillering variety of spring oats, and Clintland, a low tillering variety. Various clipping treatments (leaving a stubble of 2.4 to 3.6 cm) and nitrogen at 0 and 112 kg/ha were applied. The average forage yields from one clipping at the 4-, 5- and 7-leaf stages were 112, 392 and 2240 kg dry matter/ha respectively, while subsequent grain yields were reduced by 9, 28 and 98 percent. Clipping after the 5-leaf stage removed flower primordia and reduced test weight. Clipping at any stage reduced lodging.

Nutrient Uptake and Lodging

The role of nitrogen, phosphorus and potassium in plant growth has been the subject of extensive research. The judicious applications of these elements often results in the increased yields. Part of this increase is brought about because the crop's resistance to lodging, to pests and to diseases is increased. However, a small imbalance in the application of these elements (either excess or deficiency) may cause highly detrimental effects to crops, often resulting in reduction of yields.

Nitrogen. The heavy applications of fertilizers, particularly nitrogenous fertilizers, has been pointed out by many workers (Gainey and Sewell, 1930; Davidson and Phillips, 1930; Raheja and Misra, 1955) as one of the main reasons for lodging in crops. Das, Raheja, and Yawalkar (1966) studied the effect of four levels of nitrogen (0, 22.4, 44.8, 67.2 kg N/ha) on lodging and various plant characters associated with lodging in six wheat varieties in a varietal cum fertilizer trial. As the doses of nitrogen were increased strength of the basal internodes was very much reduced. The effect of nitrogen fertilization on several rice varieties was studied by Graves (1963) both in flooded and nonflooded fields. The first 30 # kg N/ha increased yield by 19.14 percent in flooded fields compared with 38.6 percent in nonflooded fields. Increases from the second 30 # kg N/ha were 17.21 percent and 17.61 percent for flooded and nonflooded fields, respectively, and from the third 30 # kg N/ha increases were only 6.43 percent and 7.5 percent. The higher levels of nitrogen increased lodging. Eagel (1963) reported that plots receiving nitrogen in the month of March became severely lodged. Studies conducted on the effects of rates and timing of nitrogen fertilization on performance of rice varieties by Sims, Hall, and

Johnson (1967) revealed that maximum yield with minimum plant height and lodging was obtained when urea was applied at 134.4 kg/ha (split into 44.8 kg/ha at seeding, 44.8 kg/ha at first flood and 44.8 kg/ha at second flood). Higher doses of nitrogen caused lodging and lower yields.

At Rothamsted, Widdowson, Penny, and Williams (1961) studied the effect of nitrogen fertilizers on spring barley. In 15 experiments conducted from 1957-1959 they observed yield increases from nitrogen fertilizer applications at every center. They concluded that dressings in excess of 67.2 kg N/ha gave only small gains in yield and caused severe lodging. Their results are presented in Table 4.

Basak, Sen, and Bhattacharjee (1962), while evaluating the effects of heavy nitrogen fertilization on lodging and on rice yields, reported that highest yields of rice were obtained with 112 Kg N/ha unless there was lodging before heading. Lodging, associated with the structural weakness of certain tissue, was aggravated by high nitrogen concentration in the soil.

At Indian Agricultural Research Institute (IARI), New Delhi, extensive studies were carried out by Malkani, Vaidya, and Misra (1959) on the effect of time of application of nitrogen on morphological characters in relation to lodging in wheat varieties. These authors pointed out that lodging percentage was increased by nitrogen application. Delayed application up to 70 days of 44.8 kg N/ha gave lesser intensity of lodging than early application. The early application of nitrogen increased shoot/root ratio and top weight of mother shoot, whereas it decreased unit length, weight and breaking strength. The property of lodging resistance was found to vary in the varieties examined. The order of varieties as regards lodging resistance was C 518 > N P 165 > N P 710 > N P 52 > N P 12. Nitrogen application

Table 4.--The effect of different rates and methods of applying nitrogen on the standing capacity* of barley in 1958 (Widdowson, Penny, and Williams, 1961).

Treatment	Degree of lodging					Mean
	Gaddesden	Herting- fordbury	Stopsley	Studham	Weathamp- stead	
No nitrogen	1	0	0	0	1	0
33.6 kg N/ha						
Broadcast	2	0	1	1	1	1
Drilled	2	0	1	3	1	1
67.2 kg N/ha						
Broadcast	4	3	4	6	2	4
Drilled	5	2	5	5	2	4
Drilled + top- dressing	5	4	5	6	3	5
100.8 kg N/ha						
Broadcast	6	4	7	7	5	6
Drilled	6	5	7	6	5	6
Drilled + top- dressing	6	5	7	7	8	7

* Marks for individual treatments indicate 0 = no lodging; 3, partly lodged; 6, badly lodged; 9, quite flat.

lowered the ratio of breaking strength/weight of mother shoot in every case. There was a fairly close association between this ratio and lodging percentage. N P 52, however, differed only slightly in respect of this ratio from the other two nonresistant varieties. Their results are presented in Tables 5, 6, and 7.

The time of nitrogen application has shown a pronounced influence on crop lodging. Singh and Takahashi (1962), working on the effect of varying date of top dressing of nitrogen on plant characters leading to lodging, reported that delaying the top dressing from 47 to 34 days before heading

Table 5.--Effect of nitrogen fertilization on lodging in five wheat varieties. IARI 1950-51 (Malanki, Vaidya, and Misra, 1959).

Variety	Treatment	Range of variation in percentage lodging	Average for treatment	Average for variety	No. of seasons
C 518	Control	8-13	11	29	2
	Nitrogen	34-59	41		
N P 165	Control	4-20	20	39	4
	Nitrogen	40-75	58		
N P 710	Control	32-50	41	53	4
	Nitrogen	53-74	64		
N P 52	Control	30-70	50	68	2
	Nitrogen	70-100	85		
N P 12	Control	64-96	80	89	2
	Nitrogen	97-100	99		

Table 6.--Effect of nitrogen fertilization on breaking strength in g of the lowest internode of five wheat varieties. IARI 1950-51 (Malanki, Vaidya, and Misra, 1959).

Variety	Treatment	Range of breaking strength of lowest internode	Average of treatment	Average of variety
		g	g	g
C 518	Control	864-898	881	859
	Nitrogen	825-849	837	
N P 165	Control	819-1069	919	864
	Nitrogen	635-980	809	
N P 710	Control	702-999	832	797
	Nitrogen	640-910	761	
N P 52	Control	854-896	875	857
	Nitrogen	801-874	838	
N P 12	Control	813-859	836	784
	Nitrogen	701-763	732	

Table 7.--Effect of nitrogen fertilization on the ratio of breaking strength of the lowest internode to the weight of mother shoot. IARI 1951-52 (Malanki, Vaidya, and Misra, 1959).

Variety	Treatment	Range of ratio, breaking strength/weight of mother shoot	Average of treatment	Average of variety
C 518	Control	110-113	112	99
	Nitrogen	83-91	86	
N P 165	Control	91-130	106	96
	Nitrogen	73-110	85	
N P 710	Control	71-109	90	86
	Nitrogen	64-108	82	
N P 52	Control	79-126	98	92
	Nitrogen	65-118	87	
N P 12	Control	90-112	101	87
	Nitrogen	61-85	73	

reduced the length of the 2nd and 5th internodes but increased the length of 1st (top) internode. Delaying from 34 to 10 days before heading had far less effect on the internode length except on the 2nd which continued to be reduced up to 20 days before heading. It also increased the diameter of the 4th internode (the critical one for lodging) and the breaking strength of the lower 10 cm of the culm. Thus the optimum time for top dressing to reduce lodging was considered to be 20 days before heading. Swearingin (1963) observed that early spring application of nitrogen resulted in high straw yield and late application increased grain yield of wheat. Where there was no lodging he observed that good yield responses were obtained from up to 89.6 kg N/ha. When lodging was serious yields decreased with increasing nitrogen. Sims, Hall, and Johnson (1967) in their studies on the effect of rates and timing of midseason nitrogen applications on performance

of short season rice varieties, observed a close relationship between time of application of nitrogen fertilizers and lodging. They reported that on silt loam soils cropped for many years, grain and head rice yields were inversely proportional to plant height, lodging and maturity and generally increased as the time of nitrogen application was delayed from 43 to 67 days from emergence. Statistically significant rate X time interactions were obtained from grain yields, head rice yields, lodging maturity and 1000 grain weight of rough rice. Generally yields of grain, head rice and 1000 grain weight were highest from 89.6 kg N/ha when the midseason portion (44.8 kg N/ha) was applied at 61 or 67 days, and were lowest from 179 kg N/ha, when the midseason portion (134.4 kg N/ha) was applied at 43 days.

The effect of nitrogen on crop lodging in combination with phosphorus and potassium has been examined by several research workers. Fisher and Smith (1960) conducted experiments on the influence of nutrient balance on yield and lodging of Texas hybrid corn No. 28. A complete factorial fertilizer experiment involving four rates of nitrogen (0, 44.8, 89.6, and 134.4 kg N/ha) and three rates each of phosphorus and potassium (0, 44.8, and 89.6 kg K/ha) was conducted on fine sandy loam. A heavy green manure crop was ploughed down before the test. Lodging was significantly increased by nitrogen alone or with phosphorus. Potassium alone or with other nutrients significantly reduced lodging. Effect of nitrogen, phosphorus and potassium on lodging of wheat was studied by Shrivastava and Yawalkar (1960). Their results revealed that increased nitrogen applications increased the length of the lowest internode and 22.4 or 44.8 kg N/ha reduced it. Twenty-two and four-tenths or 44.8 kg N/ha applications as ammonium sulphate increased lodging. Similar rates of phosphorus increased

lodging slightly and 44.8 kg K/ha reduced lodging compared to 22.4 kg/ha of the same. Widdowson, Penny, and Williams (1962) while studying the effect of nitrogen and potassium on barley pointed out that potassium had little effect on the straw strength and standing capacity in a wet season but nitrogen increased lodging and reduced grain size. At IARI, New Delhi, Malanki and Shrivastava (1958) conducted studies on the effect of nitrogen and nitrogen plus potassium in relation to lodging in two varieties of wheat (varieties N P 165 and N P 170). They observed that heavy application of nitrogen (89.6 kg/ha) increased lodging in wheat. They also pointed out that addition at 89.6 kg K/ha did not significantly reduce the nitrogen-induced lodging. As the application of nitrogen increased lodging, the increase in yield obtained by application of nitrogen was partially reduced by lodging. Their results are presented in Table 8.

Table 8.--Effect of fertilizers on lodging of two varieties of wheat (Malanki and Shrivastava, 1958).

Treatment	N. P. 165			N. P. 710		
	Yield in kg/ha	Loss per hectare in kg due to lodging	Corrected yield in kg/ha	Yield in kg/ha	Loss per hectare in kg due to lodging	Corrected yield in kg/ha
Control	1675.5	000.0	1675.5	1809.9	000.0	1809.9
89.6 kg N/ha	2587.2	326.6	2923.9	2337.4	590.1	2927.6
89.6 kg N/ha + 89.6 kg K/ha	2294.9	259.2	2554.1	2112.3	427.5	2539.8

Coculescu (1963) reported that response of wheat varieties he studied

to nitrogen application decreased with decreasing resistance to lodging. He observed good response to phosphorus only with less lodging resistant varieties, and there was no response to potassium. Studies conducted by Kampf (1943) on the effect of nitrogen on increased lodging resistance of wheat varieties revealed that application over 40 kg N/ha had caused lodging. Simultaneous application of potassium was found necessary to counteract the effects of high nitrogen. Spahr (1960), while determining the effect of various factors on root breaking point and on breaking strength of stem in relation to lodging in spring barley, reported that root breaking point was increased by phosphorus and to a lesser extent by potassium. He observed that nitrogen lowered the breaking point resulting in lodging.

Tubbs (1930), in his physiological studies on plant nutrition, investigated the effect of manurial deficiency upon the strength and anatomical structure of barley straw. He observed that the strength of the succeeding internodes of fully manured plants fell off rapidly. Nitrogen and phosphorus deficiency resulted in a large increase in the strength of lowest internodes, while potassium starvation decreased the strength of lowest internodes and increased that of middle internodes. His results are presented in Table 9.

These results point out indirectly that the strength of the barley straw will be reduced by application of manures.

Miller and Anderson (1963), from their studies on relationship in winter wheat between lodging, physical properties of stems and fertilizer treatments, reported that the incidence of lodging increased directly with increasing applications of nitrogen or phosphorus. They also observed that the fall applications of fertilizers caused more lodging than spring applications.

Table 9.--Force in grams weight required to crush one centimeter length of straw (Tubbs, 1930).

Internodes numbered from top downwards	Fully manured	N deficient	P deficient	K deficient
1	229	241	151	231
2	347	445	306	508
3	465	798	572	764
4	771	1604	1000	813
5	1407	2543	2097	693

Phosphorus. Phosphorus along with nitrogen and potassium is characterized as a major nutrient element, though it occurs in smaller quantities in plant tissues than the other two. The role of phosphorus has been associated with early maturity and increased root growth of crops. Reduction in growth may be caused by shortage of phosphorus. Its function as a constituent of nucleic acid, phytin and phospholipids has been known for a long time.

An adequate supply of phosphorus is associated with greater strength of central straw. The quality of certain fruit, vegetable, forage, and grain crops is said to be improved and disease resistance increased when they are adequately supplied with phosphorus (Tisdale and Nelson, 1966, pp. 77-80). Excess of phosphate over the amount required by the crops sometimes depresses crop yield. This is particularly observed in light soils in dry years and has been attributed to the hastening of the maturation processes and consequent reduction of vegetative growth (Russell, 1961, pp. 39-40).

Peken (1959) in his studies on the effect of fertilizers on the anatomical structures of stalk and the resistance of summer wheat to lodging observed that spring application of 3 metric centners P_2O_5 /ha (150 kg/ha) before harrowing was sufficient to prevent wheat from lodging and give higher yields. Phosphorus improved the morphological and anatomical properties of summer wheat; the stalk became shorter and was distinguished by a bigger diameter. The tissues had more cells and higher degree of liquefaction and formation of fibro vascular bundles increased. The sclerenchyma cells were denser and better developed over the vascular bundles.

Peterburgskii and Peken (1953) stated that superphosphate decreased lodging of spring wheat and increased yields on mountain meadow soils in east Kazakhstan. These soils are well supplied with moisture, rich in nitrogen and potassium but poor in phosphorus.

The effects of applied nitrogen and phosphorus on the nitrogen and lignin contents of the uppermost three internodes of 8 varieties of winter wheat were investigated by Miller and Anderson (1965). The nitrogen content was increased by nitrogen and phosphorus and it increased in each internode from the 3rd upwards. The lignin content in each internode from the 3rd upwards, was unaffected by the level of applied nitrogen and was decreased by phosphorus. Place and Sims (1965) reported that on silt loam soils phosphorus applied to rice at preplant, or at midseason in combination with nitrogen increased lodging and decreased grain yield. Grain yields at 89.6 kg P/ha were approximately 560 kg/ha less than with no phosphorus. Lodging increased from 61.7 to 81.3 percent with phosphorus application. Wahhab and Ali (1962) also observed similar trends of phosphorus application on lodging

treatment with high level of phosphorus alone or phosphorus with nitrogen caused most lodging.

Potassium. Potassium is one of the essential elements in the plant nutrition and one of the three major elements that are generally available in insufficient quantities. Potassium is required in synthesis of protein and amino acids. It is also important in photosynthesis as its absence leads to low rates of CO_2 assimilation. Plants with potassium deficiency are stunted in growth and leaves are small, ashy grey in color and die prematurely. With large supplies of nitrogen relative to potassium the leaves are inefficient in photosynthesis. Most of the undesirable effects such as susceptibility to fungal and bacterial diseases are attributed to the inadequate quantities of potassium in soil in the presence of high concentrations of nitrogen (Russell, 1961, pp. 39-40).

Potassium is absorbed by the plants in larger amounts than is any other mineral element except nitrogen and it is highly mobile. It is translocated to younger meristematic tissues if a shortage occurs. The deficiency symptoms are first noticed on the lower leaves of the annual plants progressing towards the top. Though it does not form an integral part of any organic compound in plants, it is considered essential in the following physiological reactions (Tisdale and Nelson, 1966, pp. 77-80):

- (1) Carbohydrate metabolism.
- (2) Nitrogen metabolism and synthesis of protein.
- (3) Control and regulation of activities of various essential mineral elements.
- (4) Neutralization of physiologically important organic acids.
- (5) Activation of various enzymes.

- (6) Promotion of growth of meristematic tissues.
- (7) Adjustment of stomatal movement and water relations.

Potassium shortage is frequently accompanied by a weakening of the straw of grain crops which results in lodging of small grains and stalk breakage in corn and sorghum.

In field trials conducted by Awan (1965) in Honduras two maize hybrids Diacol H-205 and Zamorano H-1, sown in potassium-rich soils were treated with 0, 40, 80 and 120 kg K/ha. Forty kg K/ha reduced lodging in both hybrids and gave a significant yield increase. All levels of potassium increased the foliar contents. Leibhard and Murdock (1965) conducted experiments to relate soil fertility, morphology and nutrient content of maize with lodging in the field. They observed two types of lodging in potassium deficient plants, (1) root lodging from poor brace root development, (2) stalk breakage resulting primarily from parenchyma disintegration in the lower part of the stem.

Fertilizer experiments conducted by Josephson (1962) on the relation between rates of potash and nitrogen applied and premature stalk senescence, revealed that plots with no applied potash had significantly more dead stalks at harvest. Reduced stalk breakage from application of potash has been generally observed.

Malanki and Shrivastava (1958) in their studies on lodging in wheat observed that heavy application of nitrogen (89.6 kg/ha) increased lodging in wheat (Vars. N.P. 165, and N.P. 710). Addition of potassium at 89.6 kg/ha did not significantly reduce the nitrogen-induced lodging.

Maize hybrid var. Texas 28 was grown over 3 years by Fisher and Smith (1960) to study the influence of nutrient balance on its yield and lodging.

All nitrogen, phosphorus, and potassium combinations of 0, 44.8, 89.6 or 134.4 kg N/ha, 0, 44.8, 89.6 kg P_2O_5 /ha and 0, 44.8, or 89.6 kg K_2O /ha were studied. Nitrogen had no significant effect on yield but phosphorus and potassium significantly increased the yields of grain. Percentage lodging was significantly increased by nitrogen with or without phosphorus and significantly reduced by potassium alone or in combination with other nutrients. Symptoms of potassium deficiency were present on plots receiving 0 to 44.8 kg K_2O /ha.

Shrivastava and Yawalkar (1960) while evaluating the effect of nitrogen, phosphorus, and potassium on lodging of wheat observed that 22.4 kg N/ha or 44.8 kg N/ha applied as $(NH_4)_2SO_4$ increased lodging, similar rates of phosphorus also increased lodging, 44.8 kg K/ha reduced lodging compared to 22.4 kg K/ha. Increasing nitrogen increased the length of the lowest internode. The weight per centimeter of two lowest internodes was increased by nitrogen and decreased by phosphorus and potassium. Breaking strength of the lowest internode was decreased by nitrogen and increased by phosphorus and potassium.

Yoshino (1963) in his physiological studies on aogare disease (blue green withering) of the rice plant observed that the disease was caused by high nitrogen, low potassium and shading which decreased the carbohydrate content of rice plant at ripening. There was a linear correlation between the physical strength of the culm and starch content of early ripening. Potassium content in the culms was also correlated with the strength of the straw. He observed that this disease may cause lodging as both phenomena are caused by the same internal conditions of the plant.

Effect of nitrogen, phosphorus and potassium was studied by Wahhab and

Ali (1962) on lodging, yield, plant characters and chemical composition of irrigated wheat. The wheat varieties, C518--resistant to lodging, C228--susceptible to lodging and C591, C271 and C217--intermediate in lodging susceptibility, were grown with nitrogen, phosphorus and potassium alone and in combination. Applied potassium reduced lodging especially in C518, whereas nitrogen increased it. In C591, applied phosphorus and potassium increased culm diameter, thickness of the culm wall, increased plant weight and strengthened the straw. In all the varieties potassium increased the height of those plants which lodged and increased culm diameter and culm wall thickness in those which remained erect. Potassium treated plants had longer lignified areas, more vascular bundles and better developed sclerenchyma.

Awan (1965) in his studies on the effect of potassium fertilizing on yield and lodging of maize, observed in a loamy soil poor in nitrogen and phosphorus but rich in potassium that 40 kg K/ha reduced lodging and increased yield of maize.

DISCUSSION

Crop Losses

It is an accepted fact that lodging costs the farmer heavily. It reduces crop yield and as well limits the increases in production that can be obtained by increased application of nutrients. The losses incurred by the farmers may be as heavy as 31 percent if lodging occurs at heading (Weibel and Pendleton, 1964). Laude and Pauli (1956) opined that the stage of the crop at which lodging occurs is the crux of the whole problem. In other studies on influence of lodging on yield and other characters, heavy losses up to 33 percent are recorded when lodging occurred 1 to 2 weeks before heading. Thus the degree of loss depends mainly on the state of development of the crop at which it occurs.

Morphological Characters and Lodging

While probing into the problem of lodging, the study of changes of morphological features that precede and succeed lodging is of great importance. Morphological characters such as the weight of organs above ground, particularly of leaves, density of stand, length of basal internodes, and root development are often associated with lodging (Bezdek, 1964).

Sechler (1961) traced out a relationship between root development and lodging resistance in oats. Lodging is positively related to the length of the root crown diameter of the coronal roots (at emergence from the crown) and inversely related the ratio of top growth to roots (dry weight). The main morphological difference between lodged and nonlodged plants are noticed in straw/grain ratio, specific gravity of the culm and percentage crude

fiber and silica content of the plants. Higher straw/grain ratio, low specific gravity of the culm, low crude fiber percentage and low silica content are the significant deviations noticed in lodged plants (Basak, Sen, and Bhattacharjee, 1962).

The investigation of Jellum (1961), Holmes (1960), and Hitaka (1962) have shown that lodging is more related to morphological characters, such as root system, stem diameter, length and solidness of the internodes and the bending of the culm at milk stage, than to the internal histological structure. The former characteristics are found to influence both the resistance to lodging as well as the translocation of the nutrients.

Perhaps it is difficult to separate the histological changes from morphological features, as the changes in both these factors are often noticed accompanying lodging. It may be more appropriate to state, that a lodged plant differs both morphologically and histologically from a non-lodged plant. Phillips, Davidson, and Weihe (1931) noted that the lignin content of wheat straw is higher in lodged plants when compared to nonlodged plants. Similar trend is also noticed in cellulose and ash content of lodged plants. Significant decrease in silica content is noticed in lodged plants. Welton (1928) suggested a close relationship between morphological and physiological factors responsible for lodging. In lodged plants dry matter per unit length of culm is found to be low, which results from a relatively low composition of lignin and various residue materials such as disaccharides, and polysaccharides or from the development of relatively small slender culms. Production of slender culms which are highly amenable to lodging is the result of direct causes such as thick sowing and planting of small seed. The average number of culms is greater in the lodged crop than in nonlodged

(Table 1).

An accurate evaluation of resistance of varieties to lodging is very difficult. Lodging depends upon a number of factors that vary greatly from year to year. Abundance of rainfall, relatively high temperature and other adverse weather conditions which commonly are associated with production of weak straw do not occur every season. Wind storms which provide a critical test of lodging resistance occur at irregular intervals. Thus it is difficult to find out one index of lodging that may be considered very reliable.

Investigations of Davis (1932) and Atkins (1938) suggest a significant correlation coefficient for lodging and length of lower internode, breaking strength of straw and several plant characters such as weight of panicles, weight of grain, weight of straws broken, height of culm and width of second leaf. Though correlation between rind thickness, crushing strength, and stalk lodging was established by many workers in corn, it remained undecided whether increasing the rind thickness, weight of a 5.1 cm section and crushing strength through breeding has any effect on grain yield. Singh, Zuber, and Krause (1969) who worked along these lines found little correlation between these three stalk traits and yield. Wilson (1930) opined that the distance between the lower internodes and the accompanying development of brace roots is the good measure to predict probable lodging under field conditions. Siko (1962) reported that the plant is liable to lodge when the index of lodging at the lowest internodes rises above 200 (via the formula suggested to evaluate the index of lodging, page 8). Miller and Anderson (1963) were able to express the lodging resistance by a numerical formula ($R = LBC/(\text{Log plant height})^2$ R = resistance; LBC = load bearing capacity). Zuber and Grogan (1961) are of the opinion that the use of thickness of

the rind as an indication of stalk strength is more advantageous than measuring both thickness of rind and crushing strength values. Thus the various methods suggested by different workers may be useful to measure the degree of lodging and the consequent losses that occur in the field. Since they have been worked out on different approaches to the problem of lodging, probably a discretionary use of these methods may be desirable to attain highest accuracy. The pattern of lodging and the degree of lodging depends upon various factors which need different methods to measure the losses.

Crop Lodging as Related to Crop Management

Lodging in grain crops is recognized as a source of loss. A high state of soil fertility and soil management systems that are desirable from the standpoint of increased crop yields, often augment the probability of lodging. So a careful balancing between the soil fertility status and the management practices is a desirable prerequisite to prevent lodging and promote yields of grain crops.

Much importance is given in deciding the optimum density of plant population per unit area. Norden (1966) reported increased lodging at higher plant population, which resulted from reduction in root density without an accompanying reduction in plant height (Table 3). This opinion is further confirmed by the findings of Hoff and Mederski (1960), Nelson (1960), Long (1961), and Mishra et al. (1963).

Besides the rate of seeding, the method of sowing is of great importance in deciding the degree of lodging in grain crops. Direct sowing appears to be suitable for the low tillering nonlodging varieties, while transplanting is beneficial for high tillering and lodging varieties

(Castillo, 1962). Narahari and Pawar (1961) attributed reduction in yield and lodging to broadcasting of seed whereas the beneficial effects such as nonlodging and increased yield are noticed in dibbled crop.

The time of sowing (season) is as important as the foregoing managerial practices in preventing lodging. Rice sown early in June gained more vegetative growth, with highest number of spikelets and grain per ear, but lodged badly (Kempanna, 1960). Abel (1961) suggested from his study on response of soybeans to different dates of planting that highest yields are obtained from the varieties sown in May and June. Delayed sowing is found to reduce the plant height followed by less lodging. Mixing of two varieties is found also to influence lodging in cereal crops. Patterson et al. (1963) opined that mixing two varieties which differ from one another in time to mature contributes highly to lodging resistance. His theory is based on the hypothesis that no more than 50 percent of the plants are susceptible to lodging at any given period of time during storms. Mechanical support is bound to be derived by one variety from the other.

The time of irrigation and the type of irrigation has its influence on lodging. Its effect is well pronounced especially at the stage of the plant when it is undergoing elongation of 3rd and 4th internodes. Deep water irrigation generally decreased lodging (Siko, 1958). Lang and Shu (1960) are of the opinion that drying of the field at late tillering stage decreases lodging by promoting root respiration.

Nutrient Uptake and Lodging

Though nitrogen is accepted as one of the limiting factors of crop growth its supply in excess is invariably followed by undesirable

characteristics such as crop lodging (Davidson and Phillips, 1930; Thakur and Shands, 1954, Raheja and Misra, 1955). These losses are traced to the reduction of crop resistance to lodging.

Studies conducted by Graves (1963) and Das, Raheja, and Yawalkar (1966) revealed that reduction in breaking strength of the wheat stems and reduction in ultimate yields of rice occurred only at higher doses of nitrogen, whereas at low rates such reduction was not noticed.

Besides the rate of application, the time of application of nitrogen fertilizers is found to influence crop lodging considerably. Eagel (1963) reported that wheat plots received nitrogen in the month of March ended with severe lodging. Sims, Hall, and Johnson (1967) concluded that lodging was minimal in rice crop when urea was applied in equal split doses at seeding, at first flooding and second flooding. Malkani, Vaidya, and Misra (1959) in their studies on the effect of time of application of nitrogen fertilizers on morphological characters and lodging of wheat observed that early application of nitrogen increased shoot/root ratio resulting in severe lodging. Similar studies conducted by Singh and Takahashi (1962) revealed that delaying top dressing of nitrogen fertilizers up to 20 days before heading resulted in less lodging in wheat. Swearingin (1963) reported that early spring application of nitrogen resulted in high straw yields, reduced the grain yields and increased lodging.

Sims, Hall, and Johnson (1967) reported that on silt loam soils cropped for many years, grain and head rice yields were inversely related to plant height, lodging, and maturity, and generally increased as the time of nitrogen application (in the form of $(\text{NH}_4)_2\text{SO}_4$) was delayed from 43 days to 67 days from emergence. Statistically significant rate X time interactions

were obtained from the grain yields.

A balanced nutrition is always found to promote crop yields. Nitrogen alone at higher doses causes crop lodging and in combination with other nutrients is found to increase yields and reduce lodging. Studies conducted by Fisher and Smith (1960) on the influence of nutrient balance on yields and lodging of Texas corn hybrid No. 28 revealed that nitrogen and phosphorus independently increased lodging but nitrogen in combination with potassium could reduce lodging significantly. Malanki and Shrivastava (1958) observed that heavy application of nitrogen (89.6 kg N/ha) increased lodging in wheat varieties. An addition of potassium (89.6 kg K/ha) reduced loss of yields due to lodging considerably. Kampf (1943) in his studies on the effect of nitrogen on wheat varieties of increased lodging resistance observed that application of nitrogen over 50 kg N/ha caused lodging. He found that simultaneous application of potassium counteracted the effects of high nitrogen in inducing lodging.

Heavy application of nitrogen has been pointed out in most cases as one of the main causes of lodging but opinion is divided over the role of potassium and phosphorus in preventing lodging. Widdowsen, Penny, and Williams (1962) and Coculescu (1963) opined that potassium had very little effect in preventing lodging, whereas Tubbs (1930) traced out a relationship between potassium deficiency and decreased strength of lowest internodes. Coculescu (1963) observed response, of less lodgable varieties to phosphorus application whereas Tubbs (1930) and Miller and Anderson (1963) reported increase of lodging with increased application of phosphorus.

In most of the cases examined potassium is found to increase yields by reducing lodging in grain crops. Investigations of Awan (1965), Leibhard

and Murdock (1965) and Josephson (1962) have revealed the usefulness of potassium in preventing lodging. Reduction in stalk breakage and lodging contributed to higher yields in all these cases.

Many research workers considered the balanced nutrition as more important in preventing lodging. Fisher and Smith (1960) proposed combination of potassium with nitrogen and phosphorus to reduce lodging. The nitrogen induced lodging is offset by potassium. Kurten (1966) further supported the balanced nutrition to prevent lodging over application of individual elements. Shrivastava and Yawalkar (1960) in their studies of the effect of nitrogen, phosphorus and potassium on lodging of wheat concluded that the breaking strength of the lowest internode was decreased by nitrogen and increased by phosphorus and potassium. Yoshino (1963) traced out a correlation between the potassium content of the culm and the strength of the straws. Awan (1965) reported increase in foliar potassium content of maize for all levels of potassium application. Wahhab and Ali (1962) shared the opinion of the above, stating that phosphorus and potassium increased culm diameter, thickness of the culm wall, increased plant weight and strengthened the straw. They opined that potassium treated plants had longer liquefied areas, more vascular bundles and better developed sclerinchyma.

Malanki and Shrivastava (1958) who differed from the above are of the opinion that addition of potassium did not reduce nitrogen induced lodging.

Of the three elements under investigation the role of phosphorus in preventing lodging appears to be least predictable. Phosphorus along with nitrogen and potassium is considered as essential (balanced nutrition) to prevent lodging but the role of phosphorus alone is not steady in the various experiments conducted.

Adequate supply of phosphorus is considered essential to increase the strength of cereal straw (Tisdale and Nelson, 1966). In the case of summer wheat Peken and Kh (1959) noticed reduction of lodging on account of spring application of superphosphate before harrowing. Such a practice improved the morphological and anatomical properties of summer wheat, the stalk became shorter and thicker. Peterburgski and Peken (1953) observed similar effects of superphosphate when it was applied to spring wheat grown on mountain meadow soils of east Kazakhstan.

Miller and Anderson (1965) attributed the reduction in lignin content in each internode from the 3rd upwards of the 8 varieties of winter wheat studied by them, to the addition of phosphorus. Increased lodging and decreased grain yield is reported by Place and Sims (1965) when phosphorus is applied to rice at preplant or at midseason. Wahhab and Ali (1962) have shown that most lodging in irrigated wheat they studied is caused by high level application phosphorus alone or phosphorus in combination with nitrogen.

SUMMARY

1. Lodging constitutes a major source of loss of yields in grain crops.
2. Lodging may be correlated with morphological changes such as, high straw/grain ratio, low specific gravity and low crude fiber percentage of plant tissue.
3. Significant decrease in silica, lignin and various residue materials such as disaccharides, polysaccharides in the plant tissue is obvious in lodged plants.
4. The rate of seeding and the method of sowing has pronounced influence on lodging. High population is conducive to lodging. Dibbling and direct sowing is preferable over transplanting for lodging susceptible varieties. Mixed cropping is better than pure crops. Too early sowings result in increased vegetative growth and lodging.
5. Nitrogen fertilizers in general increase lodging and cause heavy loss in grain crops. The rate of nitrogen application and time of application has an influence on lodging.
6. Nitrogen applied along with potassium increase yields and decrease lodging. Potassium acts as a corrective and counteracts the harmful effects of nitrogen.
7. Therefore, correct crop management, and application of optimum doses of nitrogen accompanied by adequate supply of potassium, may be considered as a preventive measure to increase crop yields and reduce lodging.

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MANAGEMENT AND MANURIAL ASPECTS OF CROP LODGING

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necessary for the well-being of the crop. However, a slight imbalance (either an excess or a deficiency) of one or more elements is bound to cause deleterious effects. The role of nitrogen has been the subject of extensive study in crop lodging. Nitrogen is now suspected to be the major element that can determine lodging in cereal crops. Many studies have shown that heavy applications of nitrogen caused high degrees of lodging in most cases. The optimum requirements for nitrogen varied from crop to crop and from season to season. The time of nitrogen application has also had a profound influence on crop lodging. Winter wheat that received nitrogen in March was found to lodge heavily, whereas later application caused less lodging. Lodging was negligible in rice when urea was applied in split doses at seeding time, at first flooding, and at second flooding.

Phosphorus alone had no apparent influence on lodging, but its effect was considerable when it was applied with nitrogen. An adequate supply of phosphorus was found to improve the strength of cereal straw. Excess applications of this element were not shown to increase lodging. Potassium is believed by many workers to play an important role in crop lodging. A deficiency of this element was frequently accompanied by weakening of the straw of grain crops. This resulted in lodging of small grains and stalk breakage in corn and sorghum. Potassium also was found to act as a corrective to harmful effects of excess nitrogen applications.

Because of the highly complex nature of the response of the crop to factors that affect lodging, great care must be taken to select the correct combination of farm management practices and manurial applications so that improved crop growth may be obtained without lodging. In developing countries, such as India, considerable research still needs to be done to determine the best system of production to employ with each cereal crop.

Lodging of cereal crops has long been a subject of great interest because of the heavy losses caused by it. Lodging affects materially both the quantity and the quality of grain produced. The degree of damage depends mainly on the completeness of lodging and on the stage of growth at which the lodging takes place. Frequently losses are found to vary between 12 and 31 percent. The loss is maximum when lodging occurs at heading stage. A great deal of research work has been conducted to assess the influence of environment, plant morphology, cell structure, and chemical properties on lodging.

This report reviews the work done so far with cereal crops by many research workers on (a) crop management and lodging, and (b) nutrient uptake and lodging. Incidentally the morphological characteristics of the lodged crop are also dealt with in detail.

Soil management practices desirable for promoting high yields often have been found to cause increased lodging. Greater plant population per unit area increased lodging in corn. Direct sowing of rice was found to be suitable for low tillering, nonlodging varieties, whereas transplanting was found to be beneficial for high tillering and lodging-susceptible varieties. Early planted crops, which produce more vegetative growth, lodged more severely than late planted crops. In most cases growing mixtures of crops that had different maturity dates resulted in less lodging and higher yields. Drying of wet land at late tillering stage promoted higher root respiration and reduced lodging.

A balanced nutrition is essential to promote crop yields. The essentiality of nitrogen, phosphorus, and potash in crop production has been known for a long time. The judicious application of these elements is