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Some Effects of Wind on the Growth of
White Clover (Trifolium repens L.)
Seedlings.

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of the requirements for the degree

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Summary.

The effects of wind velocity on Trifolium repens L. cv Grasslands Huia white clover seedlings were examined in a wind tunnel. Three experiments were conducted, each at a different wind velocity, in which the wind was applied to the seedlings at three distinct stages of growth (cotyledons, unifoliate leaf, and trifoliate leaf) for three periods of time (2, 4, and 6 days). The wind velocities were 5.0, 7.5, and 10.0 m/sec. In all three experiments total plant, shoot and root dry weights and root/shoot ratios were determined after 28 days. Relative growth rates both during and after the application of wind were determined for the three stages of growth and the three wind durations. In one experiment, leaf area, leaf area ratio, net assimilation rate, relative water content, transpiration rate and stomatal aperture determinations were made. Response surfaces were derived where possible to facilitate the identification of significant trends which formed the basis of discussion rather than significant values. All three wind velocities had a marked effect on total plant, shoot, and root dry weights and root/shoot ratios. Relative growth rates during the application of wind were generally higher at 5.0 m/sec than at 10.0 m/sec. They were also higher at the unifoliate stage of growth than at either the cotyledon or trifoliate stages of growth during wind application. After the application of wind, the trends of response were reversed. Wind duration generally had little effect. In the one experiment where net assimilation rates were measured, the pattern of response both during and after the application of wind was similar to that of the relative growth rates. The relative water content determinations indicated the existence of water stress which was alleviated when the wind ceased. Wind generally had no effect on the rate of transpiration but closed the stomata of the most prominent leaves. The relevance of the results to the field situation is discussed.

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Chapter 1.Review of the Literature.1 : 1 Introduction.

In a study such as the one described in this thesis, a review of the literature entails a commentary on a wide range of subjects. Accordingly, only the aspects that are directly applicable are discussed.

1 : 2 Effects of Wind on Plants.

Whitehead (1957) proposed a classification of plant response to wind based on field studies with artificial shelter and laboratory wind tunnel studies. 'Exposure evasive' plants (e.g. rosette plants) were unaffected by continuous high wind velocities whereas 'exposure tolerant' (e.g. Hordeum vulgare) and 'exposure sensitive' (e.g. Senecio nebrodenis) plants exhibited slight and marked height reductions respectively.

Plant response to wind has generally been studied by measuring the response due to either shelter (natural or artificial) or to artificial winds. Tanaka (1968), however, attempted to determine the response of plants to wind by determining the relationship between turbulence and the linear response of a plant using spectral analysis.

The effects of shelter on plants and the microclimate surrounding them have been described by Jensen (1954), Marshall (1967), and Rosenberg (1967).

Reduction of wind velocity on the leeward side of a windbreak is a function of the windbreak dimensions, position and permeability (Marshall 1967). Sturrock (1973) states that the primary effects of shelter are an improvement in the water balance, reduced potential evapotranspiration, and better use of the available water by plants. Shah (1962) concluded that the major effects of wind reduction were higher temperatures, reduced transpiration, better conservation of soil moisture, and less mechanical injury. In bean and maize plants, these effects resulted in larger leaf areas, smaller root/shoot ratios, and increased crop yield. Sturrock (1973) reported higher root weights

often associated with increases in leaf area, in sheltered soybean plants and suggested that a bigger root system could mean an improved ability to extract water from the soil. Marshall (1967) observed that a major problem encountered in interpreting the results of shelter belt studies is that soil moisture is often confounded with wind velocity. In the few studies in which the effects of soil moisture had been virtually eliminated, contradictory results had been obtained.

Brown & Rosenberg (1971, 1972) in a series of experiments, attempted to define microclimate changes in response to shelter using energy budget techniques. They concluded that a windbreak traps water vapour in the air and excludes CO_2 from the air immediately above a protected crop. The depletion of CO_2 is, however, insufficient to affect photosynthesis. They also reported that shelter has a maximum effect on crop yields when they are generally low and a negligible effect when they are generally high. In the light of this work and that mentioned earlier, it would appear that the major effect of shelter on crops is to reduce the degree of water stress that would otherwise be induced.

Artificial winds have been used to study the effects of wind on transpiration (Martin & Clements 1935, Jensen 1954, Shah 1962, Whitehead 1962, Whitehead & Luti 1962, Macklon & Weatherley 1965, Kalma & Kuiper 1966, Tinklin & Weatherley 1968) ; heat transfer (Gates 1968, Drake et al 1970, Gates & Papiian 1971, Parlange et al 1971,) ; photosynthesis (Denke 1931, Heinke & Hoffman 1935, both cited by Warren Wilson & Wadsworth 1958, Wadsworth 1959, 1960, Huht et al 1967 ,) ; respiration (Todd et al 1972) ; plant anatomy and morphology (Whitehead 1957, 1962, 1963a, 1963b, 1963c, 1965a, 1965b, Whitehead & Luti 1962).

Kalma & Kuiper (1966) cited Stalfelt (1932) who in short term experiments, observed a linear relationship between transpiration and wind speed up to 0.5 m/sec. Martin & Clements (1935) in short term studies of 24 hours found that for wind velocities up to 0.9 m/sec, transpiration was increased and maintained at a level 20 to 30 % above control in Helianthus annuus plants. At higher wind speeds, they reported an initial rapid rise in transpiration followed by a decrease which they attributed to stomatal closure. Yamaoka (cited by Kalma & Kuiper 1966) found that an increase in wind speed from 0 to 1.0 m/sec

decreased transpiration but at higher wind speeds, transpiration remained constant. Whitehead (1962) and Whitehead & Luti (1962) observed decreases in the transpiration rates of H. annuus and Zea mays plants grown under conditions of continuous wind over a five week period. Kalma & Kuiper (1966) in an experiment of three weeks duration found that the total water use of Phaseolus vulgaris plants decreased with wind speeds up to 1.6 m/sec. Macklon & Weatherley (1965) and Tinklin & Weatherley (1968) found that low wind speeds (1 - 2 m/sec) had no effect on the transpiration rate of Ricinus communis plants grown in water culture. In the short term, in sand or soil culture, it would appear that transpiration will increase in response to wind speeds up to 1.0 m/sec but thereafter will decrease, while in the long term, transpiration is likely to decrease or at least remain constant.

The effect of wind on the heat transfer processes of plants is complex. Idso & Baker (1967) reported that while reradiation was overwhelmingly the dominant mode of heat transfer in a soybean crop, transpiration transfer of heat was much more important than convection transfer. Drake et al (1970) found that for Xanthium strumarium leaves, wind affected the partitioning of energy transfer between transpiration and convection. When leaf temperature was above the air temperature, an increase in wind velocity caused an increase in convective heat loss and decreased transpiration, whereas when leaf temperature was below air temperature, an increase in wind velocity caused convective energy addition to the leaf and also increased heat loss by transpiration. Gates (1968) and Gates & Papian (1971) have demonstrated quite conclusively the importance of transpiration in heat transfer processes. They used a wind tunnel to study the effects of leaf dimensions and wind velocity on boundary layer resistance to both transpiration and convection heat transfer. They derived constants of best fit so the the complete energy budget of a leaf could be solved. By varying two factors of the equation at a time they found that, leaf dimensions largely determined external diffusion resistance because the larger the leaf, the thicker the boundary layer. Gates (1968) was able to demonstrate that plants with small leaves would be better adapted to dry hot conditions than plants with large leaves which would be better adapted to hot humid conditions. He also demonstrated that wind velocities less than 0.5 m/sec had a big influence on transpiration and

leaf temperature by reducing the thickness of the boundary layer. At wind velocities greater than 0.9 m/sec, boundary layer thickness had no effect on the heat transfer processes because the resistance of the layer was negligible.

Prior to 1958, eight groups of workers had examined the effects of artificial wind on the dry weight of whole plants (Wadsworth 1959). Of these, six reported that an increase in wind velocity resulted in decreased growth. The remaining two groups had reported an increase in CO₂ uptake and assimilation rate with increased wind velocity. Warren Wilson & Wadsworth (1958) considered that these apparently contradictory results could be reconciled. The first group of workers used wind speeds of between 2.2 and 27 m/sec while the second group used wind speeds between 0.0005 and 0.9 m/sec. They considered that there was an optimum wind speed for plant growth, i.e. the first group of workers used wind speeds above this optimum while the second used wind speeds below it. Wadsworth (1959) using a growth analysis approach and wind speeds between 1.2 and 12.0 m/sec found by extrapolation that the wind speed for optimum growth of Brassica napus grown in sand culture was 0.3 m/sec. When the plants were less than 1 cm tall, relative growth rate and net assimilation rate increased with wind speed, plants 1 - 4 cm tall exhibited an optimum wind speed for growth, and plants 4 - 7 cm tall exhibited a decrease in relative growth rate and net assimilation rate as wind speed increased. Wadsworth (1960) extended his work to include Hordeum vulgare and Pisum sativum but used a water culture technique instead of sand culture and wind speeds between 0.3 and 4.0 m/sec. He found no significantly different relative growth rates or net assimilation rates between wind speeds and concluded that the reductions reported in his previous experiment were due to partial drying out of the plants.

Todd et al (1972) reported increases in the rate of respiration (20 to 40 %) of several plant species in response to wind speeds of 7.2 m/sec under temperature controlled conditions with the rate of respiration returning to the initial rate within a short time of the wind being stopped. They suggested that elevated respiration rates such as they had measured might interfere with net assimilation and could be responsible for lower plant yields in windy regions.

Whitehead (1965a) reviewed his previous work (Whitehead 1957, 1962, 1963a, 1963b, 1963c, Whitehead & Luti 1962) and suggested that exposure to wind resulted in phenotypic changes (anatomical and morphological) enabling a plant to withstand its environment better. He summarised these changes as ;

1. reduced leaf area,
2. shorter internodes,
3. increased root/shoot ratio,
4. increased amount of vascular tissue,
5. increased number of stomata per unit area but decreased size,
6. reduced water loss per unit area, and
7. general development of xeromorphic characters.

In the series of experiments listed above, Whitehead found that Z.mays and H.annuus yields were reduced by continuous winds of 14.8 m/sec for 40 and 30 days respectively. He then grew H.annuus plants under different soil water potential regimes and found that at low soil water potentials, the plants had similar anatomical and morphological characteristics to those exhibited by plants exposed to a continuous wind for a period of time. Plants grown at low soil water potentials were better able to withstand lethal winds (17.9 m/sec) than plants grown at high soil water potentials. Humphries & Roberts (1965) challenged Whitehead's conclusion that wind and soil moisture induced similar anatomical changes and that these changes led to reduced water loss from the plant. They contended that Whitehead's data could be satisfactorily explained in terms of induced changes in root distribution and leaf area. They suggested that Whitehead's supposed technique of watering could have led to root concentration in the tops of the pots. Whitehead (1965b), however, refuted their hypothesis convincingly, pointing out that his technique of watering involved the injection of water at several points in the root zone and that as such, this would not lead to a redistribution of the roots.

To simulate field conditions in a wind tunnel is a virtual impossibility but it is possible to model turbulent boundary layer flow to a limited extent (Wooding 1968) and it is probably better to do this than to use laminar flow. Water vapour, CO₂, and energy exchange processes in the field are turbulent diffusion exchanges and hence the necessity to model turbulent flow as well as possible. High mean wind

velocities for extended periods of time do not occur in the field. Finnell (1928) used a mean wind velocity of 7.0 m/sec for sixty 24 hour days and Whitehead & Luti (1962) used a 18.0 m/sec wind for forty 24 hour days.

In regions where surface winds are a dominant part of the environment, calm periods frequently occur at night. During such periods, plants can replenish the water deficits that must occur under such windy conditions. However, in all eight studies where the effects of artificial wind on plants has been examined, no cognisance of this effect has been indicated. Hence it is probably reasonable to suggest that the effects of artificial wind on plants reported to date must be interpreted in terms of the techniques used (i.e. sand culture, water culture etc.) and considered as extreme effects. It would seem necessary to attempt some simulation of the number of hours per day that wind actually blows before the effects of wind created in wind tunnels can be accurately established.

1 : 3 Wind Tunnels.

Bain et al (1971) described two basic types of wind tunnels used in the investigation of engineering problems ; open circuit and closed circuit tunnels. In many instances, however, the specifications and requirements of wind tunnels used for the investigation of agricultural problems are different to those required in engineering investigations. Wooding (1968) described some possible applications of low wind speeds tunnels in agriculture ;

1. investigation of turbulent boundary layers,
2. investigation of turbulent diffusion,
3. investigation of wind erosion,
4. investigation of shelter effects,
5. investigation of evaporation and plant transpiration, and
6. investigation of dynamic wind effects on plants.

Wind tunnels have also been used to study the flight patterns of insects, fungal spore and pollen grain distribution by wind.

Wooding (1968) classified wind tunnels as follows ;

1. the closed circuit blower tunnel driven by a single axial fan,
2. the open circuit suction tunnel with the fan (s) downstream of the

the working section, and

3. the open circuit blower tunnel which often has a centrifugal fan upstream of a settling chamber.

Weatherley & Barrs (1959) described a climatological tunnel of the same basic type as Wooding's class 1. It has subsequently been used in the investigation of plant transpiration e.g. Macklon & Weatherley (1965). Open circuit tunnels (Wooding's class 2.) have been used to investigate the effects of shelter (Jensen 1954, Shah 1962) on growth and also plant physiological processes (references cited in section 1 : 2). Wadsworth (1959) used a tunnel of this type except that it had a variable area which enabled him to study the growth of plants under identical conditions with the exception of wind speed. Tunnels of Wooding's class 3 are relatively few in number because of the large cost involved in their construction. Tunnels of this type have been used primarily in the study of microclimate and turbulent diffusion processes.

1 : 4 Effects of Water Stress on Plants.

Over the last decade or so, numerous reviews of the effects of water stress on plant growth, physiological and metabolic processes have been published (Kramer 1959, Stocker 1960, Vaadia et al 1961, May & Milthorpe 1962, Kramer 1963, Henckel 1964, Gates 1964, Fischer & Hagan 1965, Slavik 1965, Shaw & Laing 1966, Peters & Runkles 1967, Salter & Goode 1967, Slatyer 1967, Vaadia & Waisel 1967, Crafts 1968, Gates 1968, Kramer 1969, Slatyer 1969, Laude 1972, Levitt 1972, and Hsiao 1973). The effects of water stress on plant growth and physiological processes only will be discussed.

Stocker (1960) considered the effects of soil dryness and air dryness on plants to be similar with both producing xeromorphic characters ;

1. smaller but thicker leaves,
2. shorter internodes,
3. increased root/shoot ratios,
4. increased amount of vascular tissue, and
5. increased number of stomata per unit area.

It is interesting to note that these features are similar to those reported by Whitehead as wind effects and lends credence to his hypothesis that wind effects are primarily moisture stress effects.

Stocker (1960) cited Simonis (1947) who grew Trifolium incarnatum in sand cultures which were watered to 80 % and 40 % of field capacity. He found that the total dry weight yield of the plant was reduced; the root/shoot ratio, the root/leaf ratio and the root/stem ratios were increased and the stem/leaf ratio decreased when the clover was grown at 40 % of field capacity. Salter & Goode (1967) in their review of the literature on crop responses to water comment that legumes such as Trifolium repens, Trifolium pratense and Medicago sativa are most productive with respect to vegetative growth, under continuously moist conditions, provided that prolonged periods when the soil is wetter than field capacity do not occur. Davidson (1969) and Engin & Sprent (1973) have reported that T. repens plants subjected to water stress in the vegetative phase of growth have increased root/shoot ratios. Salter & Goode (1967) also found that for the above legumes , moisture conditions suitable for maximum growth up to flowering provide the greatest potential for seed production, but that during flowering a reduction in water supply could assist setting of the seed. In the final stages of development, dry conditions could prevent loss of seeds due to in situ germination.

The stage of ontogeny at which a plant is subjected to water stress can influence both its vegetative and reproductive yield. Slatyer (1969) states that both initiation and differentiation of the vegetative and reproductive primordia are very sensitive to water stress. Gates (1968) found that initiation of foliar (vegetative) primordia in lupin plants was very sensitive to water stress and that initiation ceased even at slight water stress. However, if the stress was neither too long nor too protracted, initiation resumed on relief of the stress. Slatyer (1969) considered that the effects of water stress on primordia are in some ways analagous to bud dormancy. Nicholls & May (1963) found that floral initiation in water stressed barley plants progressively slowed. If the water stress was mild, then upon relief of the stress, initiation occurred at a slightly higher rate than in the control plants. If the stress was severe, total spikelet number was permanently reduced. In grain sorghum, however, a similar process is not evident for the imposition of a severe water stress during floral initiation merely suspends development which is resumed on relief of the stress with no significant differences from the control plants apparent (Slatyer 1969).

Water stress during anthesis can markedly reduce fertilisation and grain set in most cereals (Slatyer 1969). He cites corn as being a very sensitive plant at this time and that germination of the pollen or the growth of the pollen tube may be impaired.

Hsiao (1973) states that in many species, cell expansion is one of the plant processes most sensitive to water stress and possibly the most sensitive of all. He notes that reduction in cell size has been correlated with reductions in the water potential of the surrounding media. For example, the steady state enlargement of maize leaves was slowed by reducing the leaf water potential to - 2 bar and completely halted when the potential was reduced to - 7 bar (Hsiao 1973). The range of turgor over which cell expansion occurs can be very narrow although the range can apparently be extended by osmotic compensation in some tissues (Boyer pers. comm.), e.g. soybean hypocotyls (Meyer & Boyer 1972) and pea roots (Greacen & Oh 1972). Gates (1968) states that physiologically young tissue exhibits greater tolerance of water stress than older tissue upon which the effects of water resemble hastened senescence. Osmotic compensation could possibly explain in part the high degree of tolerance to water stress exhibited by young tissue. While Hsiao (1973) concedes that the above reported studies indicated reasonably conclusively some osmoregulation, he contests that this is a general mechanism. He cites changes in cell wall extensibility and the threshold turgor as also allowing cell expansion to continue under water stress.

Kramer (1969) considered that cell division is affected by water stress but much less so than cell expansion. Hsiao (1973) observed that the effect of water stress on cell division may not be direct but could possibly be indirect through suppressed cell expansion and also growth hormone effects.

Hsiao (1973) noted that stomatal closure is the main cause of transpiration decline as water stress develops. He also observed that an increase in stomatal resistance through closure of the stomata need not necessarily cause a proportional decrease in transpiration because leaf temperature could rise concurrently with a consequent increase in the water vapour concentration inside the leaf. Heat transfer processes and the role of transpiration were discussed in section 1 : 2. Some threshold values of leaf water potential above which stom -

atal opening is constant are - 7 to - 9 bar for tomato, - 10 to - 12 bar for soybean, and - 12 to - 16 bar for grape (Hsiao 1973). A steady decline in stomatal aperture at leaf water potentials below the threshold values is observed. Cuticular transpiration can be a significant contributor to total transpiration (10 to 90 %) according to Crafts (1968). Levitt (1972) considered that low cuticular transpiration could account for the superior drought resistance of some plants e.g. Pinus halepensis over Pinus spirea. Unique relationships between leaf water potentials, leaf water contents and transpiration rate have not been reported. This is understandable when the complex of factors that control transpiration are considered.

When the reproductive structures of a plant are fully formed, seed filling is entirely dependent upon photosynthetic activity and translocation of the assimilates to the seed. Slatyer (1969) observes that water stress at this time can have a marked effect on yield. Water stress is generally reported in the literature as causing a reduction in net photosynthesis (e.g. Vaadia et al 1961, Kramer 1963, Crafts 1968, Wardlaw 1967, 1969, 1971). Hsiao (1973) maintains that there is almost unanimity of opinion that much of the reduction in CO_2 assimilation in light during water stress is due to stomatal closure. Slatyer (1969) maintains that net photosynthesis is progressively reduced by water stress and that both the photosynthetic apparatus and gross photosynthesis are relatively insensitive to water stress, at least until a severe stress exists. In cotton plants, net photosynthesis reduction could be completely attributed to stomatal closure until a severe water stress existed (Troughton 1969). Hsiao (1973) considered that non-stomatal effects on net photosynthesis brought about by mild or moderate water stress were established in some plants. Boyer (1973) in soybean plants was unable to attribute directly to either the chloroplast membrane system or the cytoplasmic enzyme system the responses that occur when the system is desiccated. He considered that the responses to water stress were more likely to be indirect results of other cellular responses to desiccation. The accumulation of abscisic acid in Brussel sprout and tomato plants (Wright 1972) during a wilting cycle suggests the involvement of growth hormones. Wright (1972) has also reported a close correlation between abscisic acid levels and stomatal closure in Brussels sprout and dwarf bean but direct effects on the photosynthetic apparatus etc. have yet to be established. The effects of stomatal closure on transpiration and photo -

synthesis have already been mentioned.

Reduced sink size has been cited as a possible reason for reduced net photosynthesis under water stress conditions (Slatyer 1969). In wheat and Lolium temulentum according to Wardlaw (1967, 1969) this is not so. He was unable to demonstrate a direct sink size effect on the rate of photosynthesis but the rate of assimilate translocation out of the leaf was reduced. Removal of competing sources of assimilate for the reduced sink size due to slowed growth offset this reduction. Wardlaw (1969) also found that water stress had little effect on phloem transport of assimilate. The photosynthetic activity of potato and sugar beet leaves has been directly related to root and tuber size (Whittingham 1972) and Wardlaw himself conceded that lack of suitable sinks could retard photosynthesis.

The effect of water stress on respiration is rather obscure because dark and photorespiration have rarely been distinguished (Slatyer 1969). Dark respiration appears to be relatively unaffected by moderate water stress whereas photorespiration appears to increase under comparable stresses (Slatyer 1969). However, the linear increase of photorespiration with temperature (Troughton & Slatyer 1969), is probably of more importance than water stress per se, in view of the fact that during water stress, transpiration is inhibited to a greater or lesser extent with a consequent rise in leaf temperature.

1 : 5 Measurement of Water Stress.

Recent reviews of techniques of measuring water stress include Kramer & Brix (1965), Slatyer (1967), Slatyer & Shmueli (1967), Barrs (1968), Boyer (1968), Kramer (1969) and Sullivan (1972).

Plant water deficits are generally described by either one or both of the following parameters, water content and water potential. Only the most common techniques will be discussed.

The water content of a leaf can be expressed on dry weight, fresh weight, full turgor weight and area bases but full turgor weight is the only satisfactory base because dry weight fluctuates diurnally, fresh weight minimises large changes in water content and is affected by dry weight changes, and area decreases when water stress is high

(Barrs 1968). Water content at full turgor can be expressed as a function of either the amount of water taken up (equation 1 : 1) or the initial water content (equation 1 : 2) (Barrs 1968).

$$\text{Water deficit} = \frac{(\text{fully turgid weight} - \text{fresh weight})}{(\text{fully turgid weight} - \text{dry weight})} \times \frac{100}{1} \quad (1 : 1)$$

$$\text{Relative water content} = \frac{(\text{fresh weight} - \text{dry weight})}{(\text{fully turgid} - \text{dry weight}) \text{ weight}} \times \frac{100}{1} \quad (1:2)$$

Relative water content is the expression most commonly used and the technique involves the floating of whole leaves or leaf discs on water until the tissue is fully turgid. The use of leaf discs can introduce errors from infiltration along the cut edges (Kramer 1969) which Barrs (1968) suggests can be minimised by maintaining sharp edges on the leaf punch and using a disc diameter no greater than 0.8cm. Hewlett & Kramer (1963) found whole leaves more satisfactory than discs for some species although the usual argument cited against the use of whole leaves is the time necessary for equilibration. A further limitation of the technique is that leaves of different species, of different physiological age, or from different environment may have similar relative water contents but different water potentials (Kramer 1969) Beta gauge determinations of water content have also been used in the laboratory.

Water potential can be measured by liquid exchange, vapour equilibrium, thermocouple psychrometry, pressure chamber, and freezing point depression techniques (Sullivan 1972). Corrective measures for errors that could arise in liquid exchange techniques (Gaff & Carr 1964) have been applied by Sullivan (1972) to sorghum plants under water stress. Sullivan considered them to be advantageous. Some workers using the vapour equilibrium technique have found it necessary to correct for respiration loss in weight (Sullivan 1972). Thermocouple psychrometry is currently considered to be the most accurate method of measuring plant water potential (Cary & Fisher 1971 , Sullivan 1972) but the technique is limited to laboratory operation. Some of the errors and operating problems associated with thermocouple psychrometers are discussed by Barrs (1968) . Results from pressure chamber determinations do not always agree closely with thermocouple psychrometer values (Cary & Fisher 1971, Sullivan 1972) and Sullivan comments

that while it appears a useful field technique it does not seem to be applicable to all plant species. Cary & Fisher (1969) found that potential measurements made with a thermocouple psychrometer and a freezing point meter had a random average difference of 2.6 bar over the range - 5 to - 30 bar. They also reported a correlation coefficient between the two techniques of 0.8 for nine species of plants. Cary & Fisher (1971) reported discrepancies between pressure chamber and freezing point measurements and suggested that pressure chambers tend to measure the water potential in the xylem elements while the freezing point meter and the psychrometer measure the potential of water in cell walls and intracellular spaces.

Other techniques which can be used for the measurement of water stress are osmotic potential, stomatal closure and leaf diffusive resistance (Sullivan 1972),

Barrs (1968) concluded that both water content and water potential measurements were useful criteria while Kramer (1969) considered that water potential is the better parameter because it is apparently more closely related to the physiological and biochemical processes which control growth. Sullivan (1972) on the other hand observed that some workers considered relative water content more significant to plant growth and development, and water potential (water activity) more important in enzymatic reactions and directions of water movement.

1 : 6 Measurement of Transpiration.

Recent reviews on the measurement of single plant transpiration include those of Franco & Magalhães (1965), Slatyer (1967), Slatyer & Shmueli (1967) and Kramer (1969).

The four methods of measuring transpiration which are commonly used are (Kramer 1969) .

1. phytometer (potted plant) method,
2. water vapour loss (gaseometric) method,
3. cut shoot (rapid weighing) method, and
4. diffusion porometry.

The phytometer method is the most widely used (Franco &

Magalhares 1965) despite the limitations of confining the root system to a small space and that sealing the container can affect water absorption by the roots through a soil aeration affect. Temperatures of sealed containers can rise to a point where plant growth is inhibited (Franco & Magalhares 1965). The cut shoot method has received considerable criticism and is not recommended as a good technique (Slatyer 1967). Increases in stomatal aperture and a concurrent surge in transpiration following the removal of a twig or leaf from a plant have been reported (Slatyer 1967). Changes in energy load and wind structure could also result in changes in transpiration when using this technique. However, this technique can probably give useful indications in the field. Water vapour loss techniques are generally regarded as very useful in basic studies carried out in the laboratory (Franco & Magalhares 1965, Slatyer 1967, Kramer 1969) and extrapolation to the field is considered dangerous where accurate estimates are more likely to be obtained from micro-lysimeter studies (Slatyer 1967) or energy balance studies under special conditions (van Bavel et al 1963). Diffusion porometers such as the gaseous diffusion porometer (Slatyer & Jarvis 1966), the differential transpiration porometer (Meidner & Spanner 1959), and the sensor element diffusion porometer proposed by Walligan (1964) will measure transpiration. The gaseous and differential transpiration diffusion porometers are laboratory instruments. The former can only be used with amphistomatous leaves whereas the latter can also be used with hypostomatous leaves. The sensor element diffusion porometer has been modified and developed into a portable instrument suitable for field use (e.g. Kanemasu et al 1969, Beardsell 1973). Morrow & Slatyer (1971) state that the calibration of all diffusion porometers depends upon the assumption of isothermality. In the field, however, leaf - air temperature differences can be considerable and they suggested that shading a leaf for 30 to 60 seconds prior to attachment of the porometer cup and also during operation would overcome this difficulty. Ehrler & van Bavel (1968) found good agreement between rates of transpiration measured by a sensor element diffusion porometer and weighing for cotton and sunflower plants.

1 : 7 Measurement of Stomatal Aperture.

Four techniques for estimating stomatal aperture are (Barrs 1968) ;

1. Lloyd's epidermis technique,

2. Sampson's surface impression technique,
3. infiltration techniques, and
4. porometric techniques.

Lloyd's technique is generally considered slow and laborious giving good results with a limited number of species only (Barrs 1968). Sampson's surface impression technique on the other hand has been used with success by many workers with highly significant linear correlations between porometer readings and stomatal aperture (silicone rubber impression) recorded (Barrs 1968). A good correlation with the infiltration technique has also been established (Macklon & Weatherly 1965). Apertures of less than 1μ are difficult to determine . Some difficulty can also be experienced obtaining impressions from some plant species . However, repeated sampling can be carried out on the same leaf without causing injury (Barrs 1968). Brown & Rosenberg (1970) described an adaptation in which a rapid drying acrylic resin is sprayed onto the leaf, removed with cello tape after drying and then mounted directly on a microscope slide. The necessity of making a positive impression is removed by this technique.

Infiltration techniques have been used primarily in the field to indicate when water deficits are large enough to warrant irrigation (Barrs 1968). Shmueli (1964, cited by Barrs 1968) considered that even for irrigation purposes, infiltration techniques were limited because skilled operators were necessary to obtain satisfactory results.

Viscous flow porometers measure changes in stomatal conductance and hence stomatal aperture. However, stomatal conductance or aperture measurements are not as meaningful as diffusion resistance measurements in most investigations concerned with stomatal control of transpiration, photosynthesis, and plant water status (Meidner & Mansfield 1968). Hence, direct measurements of stomatal aperture have limited application except as general indicators. Direct measurements of transpiration and internal diffusive resistance using diffusion porometers are probably of more value.

Chapter 2Methods.2 : 1 Introduction.

The examination of some of the effects of wind velocity on clover seedling growth attempted in this thesis was prompted by the observation that high velocity dry winds are a frequent occurrence during the autumn and spring months in the hill country of the Wairarapa. These winds cause the topsoil of exposed faces to dry out rapidly with consequent cessation of growth. Development of these faces is frequently attempted by oversowing with clovers and applying phosphatic fertilisers and lime. It was considered that high velocity winds, such as those that occur could influence the success of overgrown clovers through moisture stress and possibly mechanical injury effects on growth.

The three experiments described were performed in a temperature controlled glasshouse of the Agronomy Department on the Massey University campus, Palmerston North.

Each experiment was of one month duration and run over the following periods ;

Experiment 1 , run during the months of February / March, 1973 ;

Experiment 2 , run during the months of March / April, 1973 ;

Experiment 3 , run during the months of November / December, 1972 .

During experiments 1 and 3, the maximum temperature setting on the glasshouse control panel was 24 C. However, the full cooling potential of the temperature control system was not utilised because this would have meant using air of relative humidity 90 % or greater and maximum day temperatures were in the vicinity of 30 C on hot sunny days as measured by a thermohydrograph. High day - time relative humidities were considered undesirable. No minimum night temperatures settings were used in these two experiments. For experiment 2, the control settings were 28 C for the day and 18 C for the night.

2 : 2 Wind Tunnel Construction.

A simple open circuit wind tunnel was constructed with

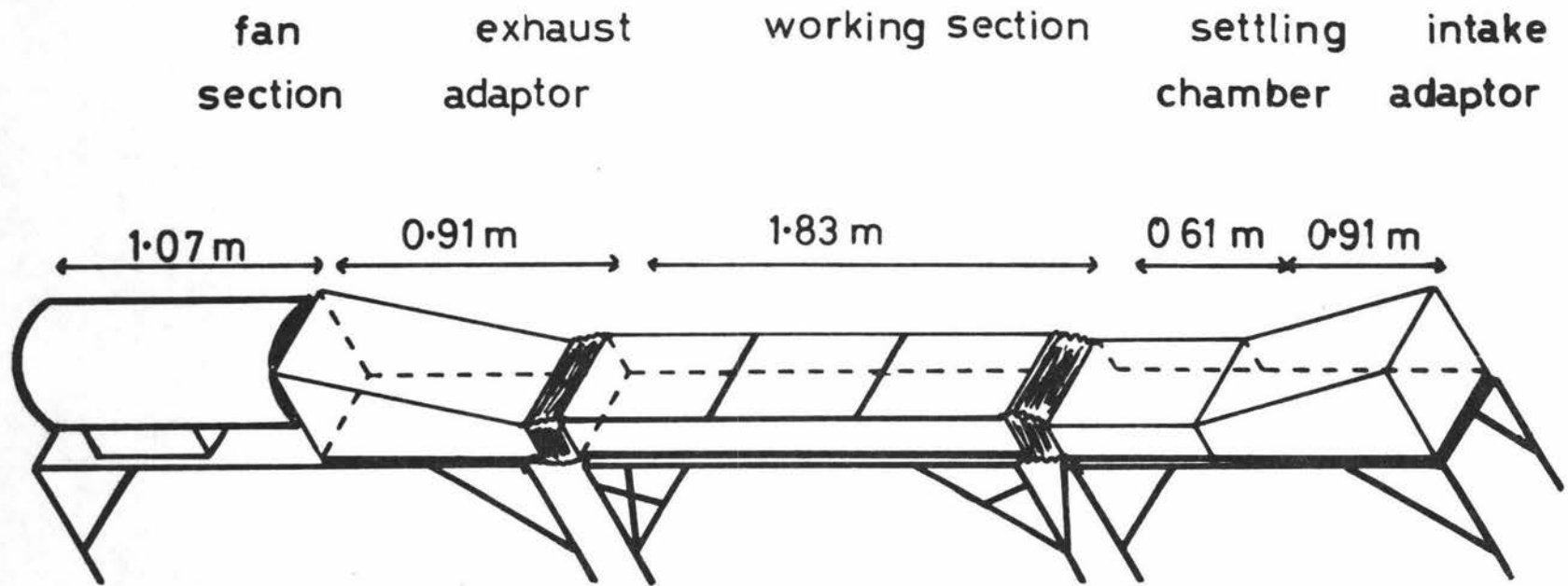


Figure 2 : 1 Wind tunnel.

dimensions as given in figure 2 : 1. The tunnel was constructed in three sections and mounted upon a dexion steel frame.

Section ' A ' contained a 37.5 cm diameter axial fan (8 adjustable pitch blades) attached to a 0.5 H.P. Wagner electric motor from which the centrifugal weight mechanism had been removed. A matched variac was placed in series with the motor and the wind velocities required were obtained by calibration with an anemometer. The variac was placed inside the tunnel to keep it cool. A time clock was placed in the circuit also. The tunnel and exhaust adaptor were made of galvanised iron sheeting with the joint between them sealed by attaching clear polythene sheeting with 2.5 cm insulation tape to each.

Section ' B ', the working section, was constructed from 0.625 cm perspex sheeting, dexion steel, and clear polythene. The perspex sides were bolted to the dexion steel frame as single pieces and a strip of foam (0.9 cm wide) placed on the top edge of each. The top of the working section was divided into three to facilitate access and secured by means of elastic luggage holders. The bottom of the working section was plywood which was supported by the dexion steel frame. Clear polythene sheeting attached to the sides with insulation tape and enclosing the plywood bottom made the working section reasonably airtight. Metal trays were placed inside the working section and the entire section supported by an external dexion steel frame.

Section ' C ', the intake adaptor and settling chamber, were constructed with galvanised iron sheeting and 0.9 cm thick plywood respectively. Only the working section joint was sealed.

By the means described, a simple and inexpensive, but nevertheless apparently effective wind tunnel was constructed in which wind speeds up to 11.5 m/sec could be generated.

2 : 3 Calibration of Wind Tunnel and Nature of Wind Flow.

Calibration of the variac was achieved by the use of a Lambrecht vane anemometer. The anemometer was placed in the centre of the working section which was filled with pots, and the mean

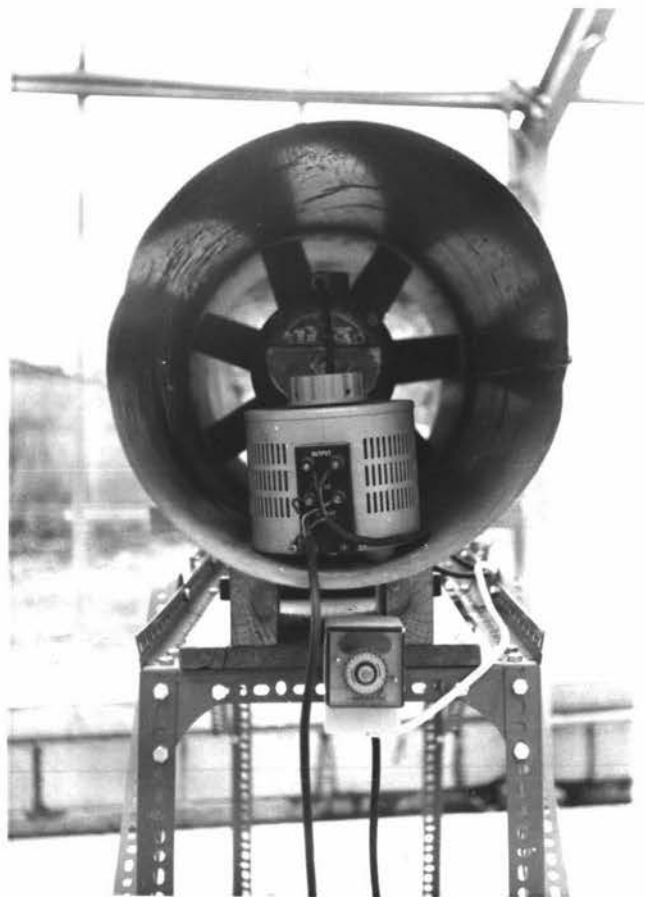


Plate 2 : 1 Wind tunnel, fan, variac and time clock.

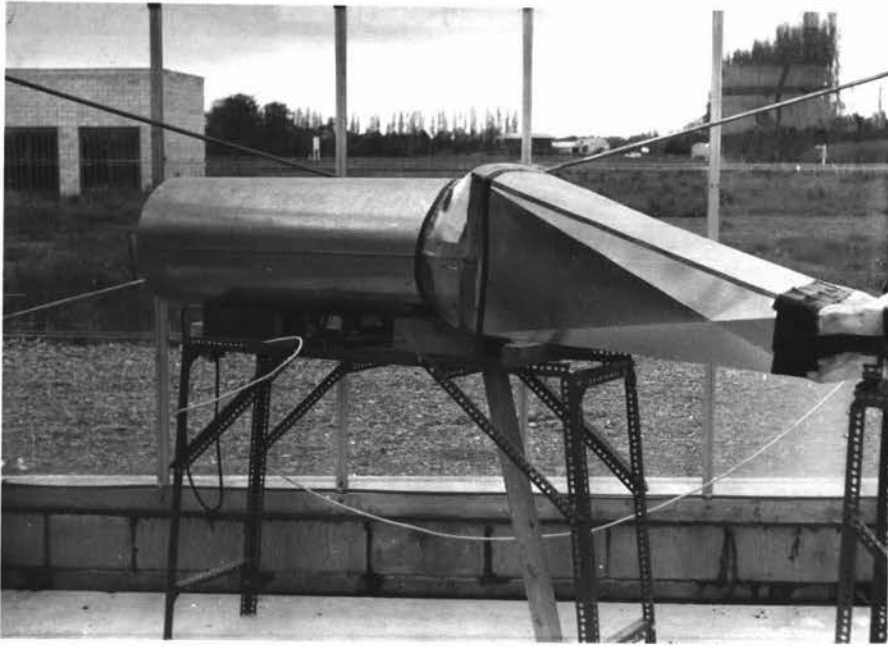


Plate 2 : 2 Wind tunnel, exhaust adaptor and fan sections.

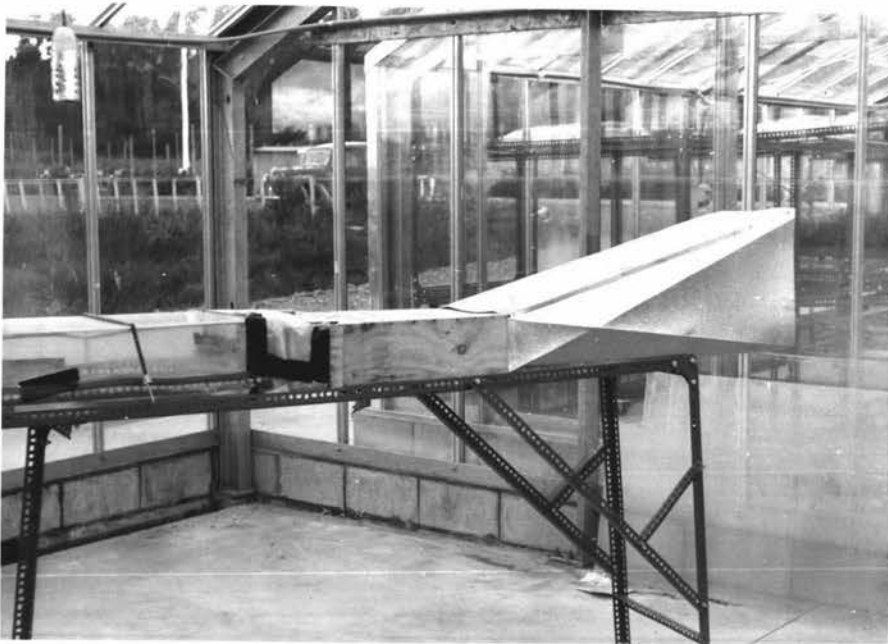


Plate 2 : 3 Wind tunnel, working section, settling chamber and intake adaptor.

wind run over a period of one minute in the secured tunnel obtained. Variac settings for the three wind speeds, 5.0 m/sec (Experiment 1), 7.5 m/sec (Experiment 2), and 10.0 m/sec (Experiment 3) were obtained in this way.

Spot checks on the wind velocity during the three experiments were made with a hot wire anemometer. The hot wire anemometer was placed about 5 cm above the pot surfaces for these checks.

The tunnel was designed to give turbulent flow over the entire working section. While this was not checked exhaustively, the turbulent nature of the air flow in the working section was demonstrated by letting small streamers extend from the intake adaptor to the exhaust adaptor. Violent movement of the streamers was always demonstrated.

It was not possible to measure the wind velocity profile obtained in the working section.

2 : 4 Experimental Methods.

2 : 4 : 1 Introduction.

All the experiments were performed using 7.5 x 7.5 cm plastic pots containing a potting mixture of 1 : 1 fine ground pumice and fine sieved peat. The pots were placed in metal trays which were filled with water to provide a sub-irrigation system. The water in the trays was topped up every 2 to 3 days with the exception of those in the wind tunnel which were topped up daily. A complete nutrient solution was applied at the rate of 50 ml per pot before the seed was sown and at 4 - 6 day intervals until the end of the experiment. This was considered adequate for nutrients to be non-limiting to growth.

All the pots were maintained in a sub-irrigated state on trolleys in the same glasshouse as the tunnel with the exception of the period in the tunnel.

Wind was applied for an 8 hour day from 8 am to 4 pm. All treatments were moved after 4 pm, whether into, or out of, the tunnel.

2 : 4 : 2 Sowing Techniques.

A commercial line of Grasslands ' Huia ' white clover of 99.8 % purity and 94.0 + 3.0 % germination was used. One hundred seeds per pot were sown on a grid system. The seeds were placed on the potting mixture surface and fine pumice was sprinkled on until all the seeds were covered.

The above technique was used on all the pots that were to be harvested at the end of the experiment. The known number of seeds was to facilitate germination counts.

Pots from which continuous harvest data, relative water content and stomatal aperture determinations were to be made, were sown by broadcasting a known weight of seed equivalent to approximately 100 - 150 seeds on the potting mixture surface and covering with fine pumice as described above.

2 : 4 : 3 Harvesting.

In general the technique consisted of washing the entire contents of a pot on a P.V.C. grid with a hose. When the plants were small, a second fine mesh was also used. A variation of the above procedure was used for the final harvests, which consisted of sub-sampling the pot and washing in the manner described above.

The washed plants (10/sample) were dissected into shoots and roots (experiments 1 & 3), or into cotyledons, unifoliate leaves, trifoliate leaves, crown and petiole, and roots in experiment 2. The plant components were dried on aluminium foil at 80 - 90 C for a minimum of 12 hours. The dry weights were measured on a Metler balance of accuracy 0.00005 g.

Leaf area determinations were made on the cotyledons, unifoliate leaves and trifoliate leaves during experiment 2. A leaf area meter (Type AAM 5, Hayashi Denko Co, Ltd.) was used for these determinations which were carried out prior to drying.

2 : 4 : 4 Relative Water Content.

Relative water content (R.W.C.) determinations were made

during experiment 2. Determinations were made on component leaves and cotyledons during wind application and two days after wind application had ceased.

The component leaves were excised and the fresh weight of the sample taken. Sample size varied according to the stage of growth at which the determinations were made. Five plants per sample were used for the stage of growth A and B determinations but only three plants per sample for the stage of growth C determination. The leaves were floated on distilled water in covered petrie dishes for six hours at laboratory temperature, blotted dry and reweighed to obtain the turgid weight. The leaves were then dried on aluminium foil for a minimum of 12 hours at 80 - 90 C after which the dry weight was taken.

R.W.C. was calculated according to formula 1 : 1 (Barrs 1968).

$$R.W.C. = \frac{(\text{Fresh weight} - \text{Dry weight})}{(\text{Turgid weight} - \text{Dry weight})} \times \frac{100}{1} \quad (1 : 1)$$

A simple experiment indicated that the period of rapid water uptake (phase I as described by Barrs 1968) was 2 hours for the cotyledons and 6 hours for the unifoliate leaves. It was decided to use a standard time of 6 hours for the three types of leaf tissue at all stages of growth.

2 : 4 : 5 Transpiration.

Transpiration measurements were made during experiment 2 using the technique described below.

Plastic specimen tubes and caps were the basic unit of the method. Five small holes were made by a hot nail in the bottom of the tube and a single big hole in the centre of the cap. The tube was painted with black bituminous paint and filled with damp potting mixture. A small piece of dialysis membrane was placed over the hole inside the cap and the cap secured on the tube. Nutrient solution was injected (2 ml / application / tube) through one of the five holes (fig. 2:2).

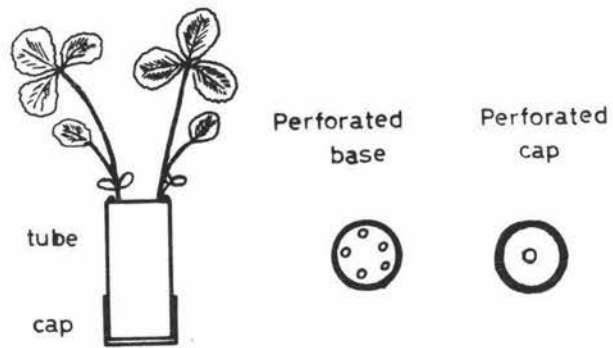


Figure 2 : 2

Transpiration Container.

Clover seeds were germinated on filter paper until the radicle was approximately 5 mm long and then transplanted into the tubes. A needle was used to make a hole in the potting mixture and the seed inserted radicle first. Four seedlings per tube were planted in this way leaving the fifth hole for the application of nutrient solution. A damp cloth was placed over the transplanted seedlings for 2 - 3 days and then removed. Survival was estimated to be about 75 %.

Prior to transpiration measurement, the hole in the cap and the cap-tube joint were sealed with wax. The holes around the plant stems were sealed with liquid vaseline extruded from a syringe. A water vapour tight seal was obtained by using a hot needle to flow the vaseline around the plant stems.

The loss in weight from such a sealed system over time was attributed to transpirational loss of water.

2 : 4 : 6 Stomatal Aperture.

These determinations were made during experiment 2 by spraying the under surface of the leaves with clear polyurethane enamel. The enamel was allowed to dry (10 - 15 minutes) and the impression removed from the leaf with cello tape. The cello tape was mounted on a slide and the impression viewed through a microscope.

2 : 5 Statistical Methods.

2 : 5 : 1 Design.

A (3 x 3) + 1 factorial design was used in all three experiments, with four replicates in experiments 1 and 3, and six replicates in experiment 2. The replicates of each treatment were blocked on a treatment basis and not on a randomised block basis. The main effect treatments are listed in table 2 : 1. A no wind control treatment was included in all three experiments.

Table 2 : 1Main Effect Treatments.Stage of growth when wind applied .

- A. Seedlings 6 days old and the cotyledons fully expanded.
- B. Seedlings 13 days old and the unifoliate leaf fully expanded.
- C. Seedlings 20 days old and the first trifoliate leaf fully expanded.

Duration of wind applied.

- D. Two 8 hour days.
- E. Four 8 hour days.
- F. Six 8 hour days.

2 : 5 : 2 Final Harvest Data Analysis.

All data was analysed by least squares analysis of variance. Polynomial response surfaces were fitted where applicable by partitioning of the sums of squares and inspection of the coefficients so obtained (Snedecor & Cox 1967). Coefficients which were significant at $P = 0.10$ or less were included in the fitted equation. The adequacy of fit was examined by least squares analysis of variance and the fitted values plotted on isometric graph paper.

2 : 5 : 3 Growth Analysis.

A minimum of four samples per treatment per harvest were taken at the following time intervals, 6, 8, 10, 12, 15, 17, 19, 22, 26, and 28 days. The final harvest values were used for the 28 day values.

The control harvest data was meaned and the means logarithmically transformed and least squares regression analyses performed using the model (2 : 2) where W = total plant weight, A = total leaf area, t = time, and C = constant of the equation.

$$\log_e W = \log_e A + C.t = A.e^{Ct} \quad (2 : 2)$$

Expression (2 : 2) transformed to base 10 logarithms yields expression (2 : 3) where $C = 2.3026 \log B$.

$$\log W = \log A + \log B \cdot t \quad (2 : 3)$$

Frequent small harvests have been used in growth analysis experiments (Freeman & Hughes 1967) and the usefulness of the technique commented on by Radford (1967) and Nicholls & Calder (1973). Such an approach allows point relationships between the growth analysis components, relative growth rate (R.G.R.), net assimilation rate (N.A.R.), and leaf area ratio (L.A.R.) to be determined (2 : 4, 2 : 5, 2 : 6.).

$$\text{R.G.R.} = \frac{1}{W} \cdot \frac{dW}{dt} \quad (2 : 4)$$

$$\text{N.A.R.} = \frac{1}{A} \cdot \frac{dW}{dt} \quad (2 : 5)$$

$$\text{L.A.R.} = \frac{A}{W} \quad (2 : 6)$$

The regression technique allowed the R.G.R.s of the control plants in all three experiments to be determined at any point in time. In experiment 2, N.A.R. and L.A.R.s were likewise determined.

Classical growth analysis techniques (Evans 1972, Radford (1967) in which mean R.G.R.s between two points in time are determined were used in all three experiments on the wind treated plants. The fitted regression equations for the control plants were used to calculate the logarithm of plant weight at the beginning of each stage of growth period and mean R.G.R.s for the period of wind duration at each stage of growth determined using equation 2 : 7.

$$\overline{\text{R.G.R.}} = 2.3026 \left(\frac{\log W_2 - \log W_1}{t_2 - t_1} \right) \quad (2 : 7)$$

R.G.R.s for the period following the cessation of wind were obtained by pairing randomly the logarithms of the treatment final harvest with the logarithms at the cessation of wind application.

The R.G.R.s for the two periods (i.e. period of wind duration and period after wind cessation) were analysed by least squares analysis of variance and polynomial response curves fitted where significant in the manner described earlier.

The R.G.R.s of the three experiments were combined to give a 3 x 3 x 3 by four replicates analysis of variance table. The R.G.R.s of the control plants in experiments 1 and 2 were found to be within the limits of their standard errors but constant factors (1.187 for the total plant and shoot R.G.R.s and 1.130 for the root R.G.R.) were necessary to adjust the experiment 3 data.

Mean N.A.R.s and L.A.R.s for the periods during and after wind application in experiment 2 were derived using equations 2 : 8 and 2 : 9 respectively. Radford (1967) states that these two equations are only valid when growth is exponential and the exponents of A and W are the same (i.e. A / W is constant over time).

$$\overline{\text{N.A.R.}} = \frac{W_2 - W_1}{A_2 - A_1} \times \frac{\log_e A_2 - \log_e A_1}{t_2 - t_1} \quad (2 : 8)$$

$$\overline{\text{L.A.R.}} = \frac{\frac{A_1}{W_1} + \frac{A_2}{W_2}}{2} \quad (2 : 9)$$

2 : 5 : 4 Relative Water Content.

R.W.C. data was analysed by treating the component leaves of the plants and the wind durations as a factorial experiment with variable numbers of replicates. Variance attributable to the replicates was included in the error term.

2 : 5 : 5 Transpiration.

The raw data was transformed to a water loss (mg) / mg of shoot tissue / minute initially and then multiplied by 480 to give a standard 8 hour day for comparative purposes. This data was mean - ed and the standard errors of the means determined. No other stat - istical analyses were performed.

2 : 5 : 6 Stomatal Aperture.

The aperture of the stomata was determined on the basis of *whether*

they were open or closed when viewed under a microscope. Twenty fields of view per plant component leaf were used to assess the aperture status. The frequency of stomata being open or closed was then determined.

Chapter 3.Results.3 : 1 Introduction.

The results of the three experiments comprising this thesis will be presented in three sections. The first will describe the final harvest data ; the second, the growth analysis data ; and the third, the R.W.C., transpiration, and stomatal aperture data from experiment 2.

3 : 2 Final Harvest Data.

Analyses of variance tables and the fitting data, where applicable, for the results given in this section are detailed in appendix I.

3 : 2 : 1 Experiment 1 (5.0 m/sec wind).

The main effects for total plant weight, shoot weight, root weight, and root/shoot ratio are given in table 3 : 1.

With the exception of a wind duration effect on root weight, there were no significant main effects. But, all the treatment main effects had lower total plant weights, shoot weights and root weights than the respective controls. Wind duration also had a significant effect on the root/shoot ratio . All the treatment main effects had significantly higher ratios than control.

3 : 2 : 2 Experiment 2 (7.5 m/sec wind).

The main effects for all the plant parameters measured in this experiment are detailed in tables 3 : 2 (leaf numbers), 3 : 3 (leaf area), 3 : 4 (plant component weight), 3 : 5 (final harvest data), and 3 : 6 (plant weight ratios).

The number of cotyledons per plant were significantly reduced at the B and C stages of growth and also by wind durations E and F. The presence of the unifoliate leaf was significantly reduced at stage of growth C with wind duration having no significant

Table 3:1

Final Harvest (Experiment 1).

<u>Stage</u>	<u>Total Plant</u> <u>Weight (mg)</u>	<u>Shoot Weight</u> <u>(mg)</u>	<u>Root Weight</u> <u>(mg)</u>	<u>Root/Shoot</u> <u>Ratio</u>
A	10.50	5.90	4.60	0.780
B	10.98	6.43	4.55	0.712
C	10.68	6.06	4.57	0.754
	n.s.	n.s.	n.s.	n.s.
Control	13.42	8.40	5.02	0.604
L.S.D. 5 %	1.55	0.88	0.71	0.067
<u>Duration</u>				
D	10.66	6.13	4.53	0.741
E	11.57	6.44	5.08	0.792
F	9.93	5.82	4.11	0.713
	n.s.	n.s.	*	*
Control	13.42	8.40	5.02	0.604
L.S.D. 5 %	1.55	0.88	0.71	0.067

* P = 0.05

* * P = 0.01

n.s. not significant

Table 3:2

Leaf Numbers per Plant (Experiment 2).

<u>Stage</u>	<u>Cotyledons</u>	<u>Unifoliate Leaf</u>	<u>Trifoliate Leaves</u>
A	1.5	0.94	2.6
B	1.0	0.97	2.6
C	1.0	0.86	2.6
	* *	* *	n.s.
Control	1.5	0.95	2.6
L.S.D. 5%	0.2	0.05	-
<u>Duration</u>			
D	1.4	0.95	2.6
E	1.1	0.93	2.5
F	1.0	0.89	2.6
	* *	n.s.	n.s.
Control	1.5	0.95	2.6
L.S.D. 5%	0.2	0.05	6

* P = 0.05

* * P = 0.01

n.s. not significant

Table 3:3 Leaf Area (cm²) Per Plant (Experiment 2).

<u>Stage</u>	<u>Cotyledons</u>	<u>Unifoliate Leaf</u>	<u>Trifoliate Leaves</u>	<u>Total Leaf</u>
A	0.10	0.27	2.03	2.40
B	0.08	0.29	1.92	2.29
C	0.07	0.23	2.03	2.33
	*	**	n.s.	n.s.
Control	0.10	0.34	2.35	2.79
L.S.D. 5 %	0.02	0.03	0.23	0.24
<u>Duration</u>				
D	0.10	0.27	2.08	2.45
E	0.09	0.26	1.88	2.23
F	0.07	0.25	2.03	2.35
	*	n.s.	n.s.	n.s.
Control	0.10	0.34	2.35	2.79
L.S.D. 5 %	0.02	0.03	0.23	0.24
<u>Interaction</u>				
	**	*	n.s.	n.s.

* P = 0.05

** P = 0.01

n.s. not significant

effect. Trifoliolate leaf numbers were not affected by the application of wind.

Cotyledon leaf area was significantly reduced at stages of growth B and C and by wind duration F. A significant negative interaction was measured. Unifoliolate leaf area was significantly reduced at stage of growth C with wind duration having no significant effect. A significant negative interaction was measured and all the treatment main effect unifoliolate leaf areas were significantly smaller than control. There were no significant main effect differences for either trifoliolate or total leaf area, although the control leaf areas for both parameters, were significantly greater.

Cotyledon weight was significantly reduced at stages of growth B and C and by wind duration F. Unifoliolate leaf weight was significantly reduced at stage of growth C and all the treatment unifoliolate leaf weights were significantly less than control. Trifoliolate and total leaf weights at stage of growth B were significantly greater than stage of growth A leaf weights and all the treatment main effects were significantly smaller than control. There were no significant main effect differences for stem weight and all the treatment main effect stem weights were significantly less than control.

There were no significant main effect differences for total plant weight or root weight but all treatment main effects for both parameters were significantly less than control. Shoot weight at stage of growth B was significantly greater than at stage of growth A with all treatment main effects significantly less than control. The root/shoot ratio at stage of growth B was significantly less than at stage of growth A and the ratios at wind durations E and F were significantly less than the wind duration D ratio. All the root/shoot ratios, with the exception of the ratio at stage of growth B, were significantly greater than control.

Both control and stage of growth B root/leaf ratios were significantly smaller than stage of growth A and C ratios with the wind duration D ratio significantly greater than the wind duration E, F, and control ratios. Stage of growth B and C root/stem ratios were significantly smaller than the stage of growth A ratio and all the

Table 3:4 Plant Component Weight (Experiment 2).

<u>Stage</u>	<u>Cotyledons</u> (mg)	<u>Unifoliolate</u> <u>Leaf (mg)</u>	<u>Trifoliolate</u> <u>Leaves (mg)</u>	<u>Total Leaf</u> (mg)	<u>Stem</u> (mg)
A	0.28	0.52	3.57	4.33	2.75
B	0.20	0.58	4.17	4.95	3.08
C	0.18	0.50	3.84	4.52	3.12
	* *	* *	*	*	n.s.
Control	0.25	0.63	5.22	6.08	4.33
L.S.D. 5 %	0.04	0.05	0.41	0.43	0.33

Duration

D	0.25	0.54	3.70	4.49	2.92
E	0.22	0.54	3.89	4.64	2.94
F	0.18	0.50	4.00	4.67	3.08
	*	n.s.	n.s.	n.s.	n.s.
Control	0.25	0.63	5.22	6.08	4.33
L.S.D. 5 %	0.04	0.05	0.41	0.43	0.33

* P = 0.05

* * P = 0.01

n.s. not significant

Table 3:5

Final Harvest (Experiment 2).

<u>Stage</u>	<u>Total Plant Weight (mg)</u>	<u>Shoot Weight (mg)</u>	<u>Root Weight (mg)</u>	<u>Root/Shoot Ratio</u>
A	11.04	7.08	3.97	0.563
B	11.97	8.03	3.95	0.495
C	11.61	7.64	3.98	0.523
	n.s.	*	n.s.	*
Control	15.21	10.41	4.81	0.466
L.S.D. 5 %	1.13	0.74	0.47	0.044

Duration

D	11.55	7.41	4.14	0.562
E	11.41	7.58	3.83	0.504
F	11.67	7.74	3.93	0.514
	n.s.	n.s.	n.s.	*
Control	15.21	10.41	4.81	0.466
L.S.D. 5 %	1.13	0.74	0.47	0.044

* P = 0.05

* * P = 0.01

n.s. not significant

Table 3:6

Plant Weight Ratios (Experiment 2).

<u>Stage</u>	<u>Root/Leaf</u> Ratio	<u>Root/Stem</u> Ratio	<u>Stem/Leaf</u> Ratio
A	0.918	1.462	0.635
B	0.802	1.295	0.622
C	0.881	1.288	0.688
	**	*	**
Control	0.800	1.120	0.713
L.S.D. 5 %	0.072	0.133	0.037
<u>Duration</u>			
D	0.927	1.432	0.651
E	0.825	1.306	0.636
F	0.850	1.307	0.658
	*	n.s.	n.s.
Control	0.800	1.120	0.713
L.S.D. 5 %	0.072	0.133	0.037

* P = 0.05

** P = 0.01

n.s. not significant

treatment main effects were significantly greater than the control ratio. Stage of growth A and B stem/leaf ratios were significantly smaller than the stage of growth C and control ratios.

3 : 2 : 3 Experiment 3 (10.0 m/sec wind).

The main effects for total plant weight, shoot weight, root weight and root/shoot ratio are given in table 3 : 7.

Total plant weight was significantly smaller at stages of growth B and C than at stage of growth A with wind duration having no significant effect. A significant negative interaction was measured. There were no significant main effect differences for shoot weight but a significant negative interaction was measured. All the treatment main effect shoot weights were significantly less than control. Root weight at stage of growth B was significantly less than at stages of growth A and C and also control. Root weight at wind duration D was significantly greater than at wind durations E and F and also control. A significant negative interaction was measured. The root/shoot ratios at stages of growth A and C were significantly higher than the ratio at stage of growth B and also control. All the wind duration main effects were significantly greater than control.

3 : 2 : 4 Response Surfaces.

Significant response surfaces for shoot weight and root weight response to wind were derived in experiments 2 and 3, and 1 and 3 respectively (fig. 3 : 1).

Shoot weight in experiment 2 exhibited a distinct stage of growth effect with a maximum at stage of growth B. The pattern of shoot weight response in experiment 3 was complex with a stage of growth by wind duration interaction. Shoot weight at wind duration E increased linearly from stage of growth A to C. Root weight in experiment 1 exhibited a slight wind duration effect and in experiment 3, the pattern of response was similar to that of the shoot weight.

Significant response surfaces for total plant weight and root/shoot ratios were derived in experiments 1, and 1, 2, 3

Table 3:7

Final Harvest (Experiment 3).

<u>Stage</u>	<u>Total Plant Weight (mg)</u>	<u>Shoot Weight (mg)</u>	<u>Root Weight (mg)</u>	<u>Root/Shoot Ratio</u>
A	10.22	5.77	4.46	0.771
B	8.11	5.02	3.10	0.618
C	9.90	5.66	4.24	0.760
	*	n.s.	* *	*
Control	10.21	6.48	3.73	0.576
L.S.D. 5 %	1.09	0.70	0.47	0.066

Duration

D	9.57	5.37	4.21	0.775
E	9.19	5.56	3.64	0.664
F	9.47	5.52	3.94	0.709
	n.s.	n.s.	*	n.s.
Control	10.21	6.48	3.73	0.576
L.S.D. 5 %	1.09	0.70	0.47	0.066

Interaction

*	*	*	n.s.
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* P = 0.05

* * P = 0.01

n.s. not significant

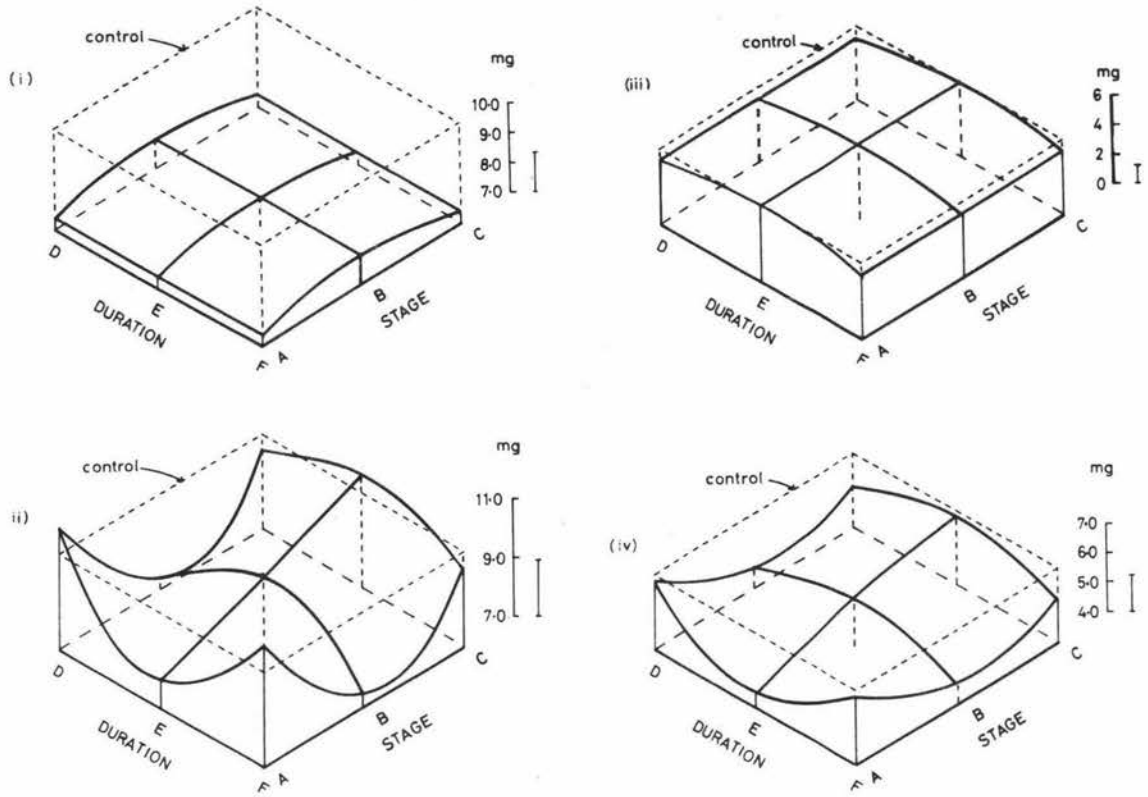


Figure 3 : 1

Response Surfaces.

- i. shoot weight (experiment 2)
- ii. shoot weight (experiment 3)
- iii. root weight (experiment 1)
- iv. root weight (experiment 3)

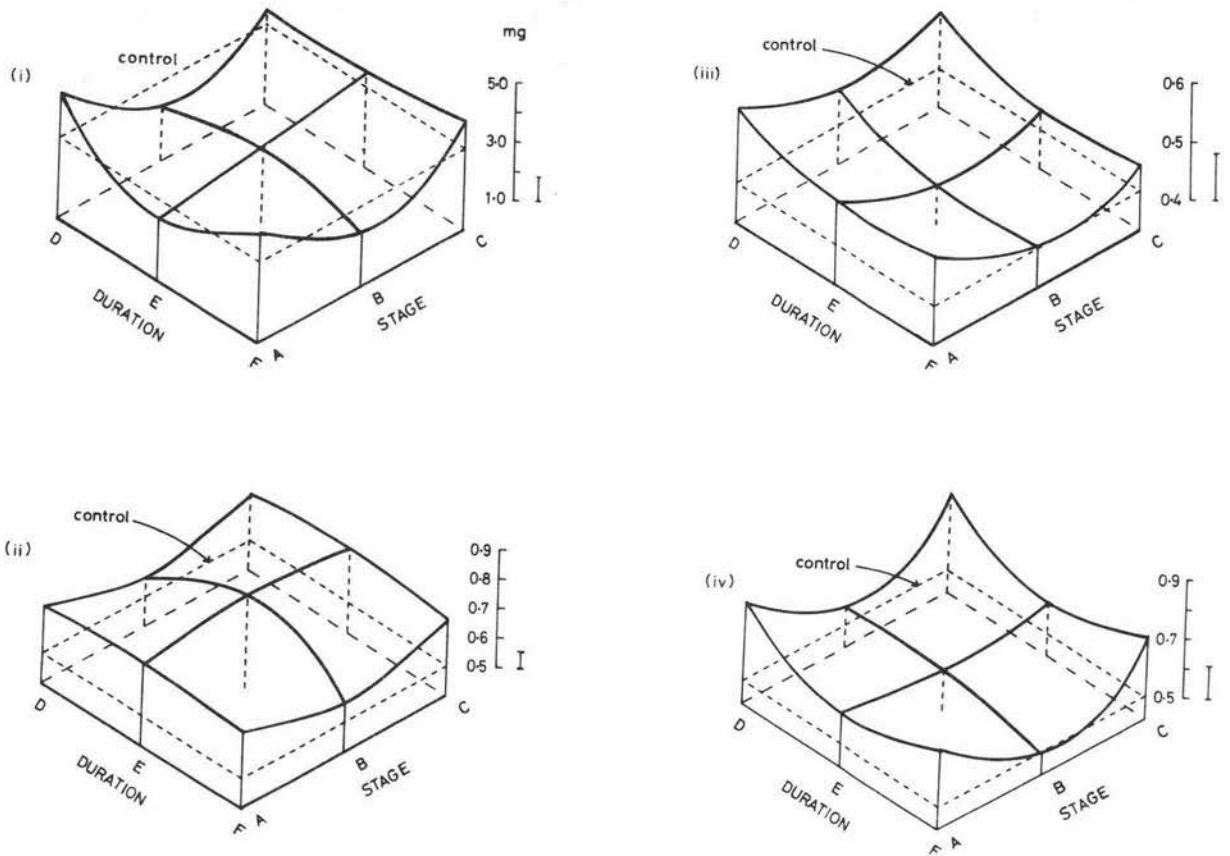


Figure 3 : 2

Response Surfaces.

- i. total plant weight (experiment 3)
- ii. root/shoot ratio (experiment 1)
- iii. root/shoot ratio (experiment 2)
- iv. root/shoot ratio (experiment 3)

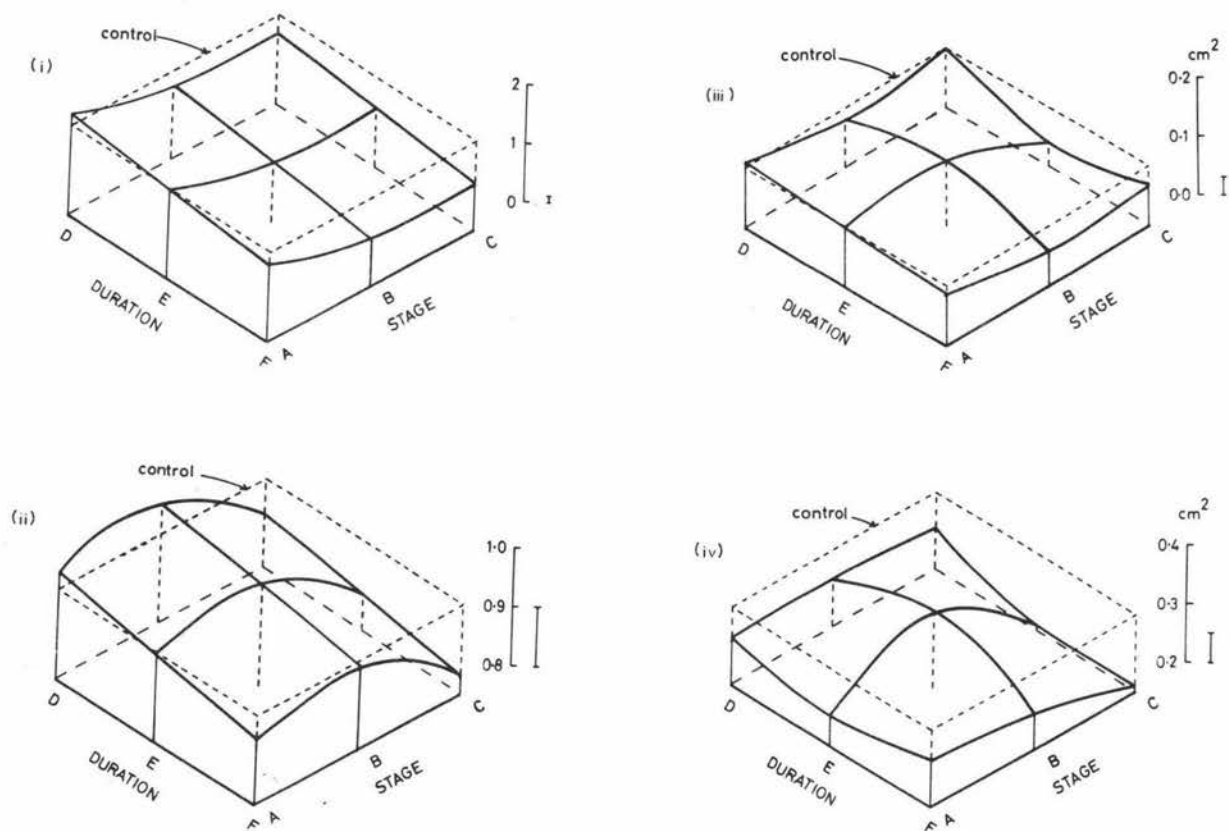


Figure 3 : 3

Response Surfaces.

- i. cotyledon number
- ii. unifoliate leaf number
- iii. cotyledon leaf area
- iv. unifoliate leaf area

respectively and are depicted in figure 3 : 2.

The pattern of total plant weight response in experiment 3 was similar to the pattern of response of both the shoot and the root. The patterns of response of the root/shoot ratios in all three experiments were essentially similar with higher ratios at stages of growth A and C than at stage of growth B.

Significant response surfaces for cotyledon numbers, unifoliate leaf numbers, cotyledon leaf area and unifoliate leaf area were derived in experiment 2 (figure 3 : 3).

Essentially similar patterns of response are exhibited with distinct stage of growth effects at wind duration F.

Significant response surfaces for cotyledon weight, unifoliate leaf weight, trifoliate leaf weight and total leaf weight were derived in experiment 2 (figure 3 : 4).

While cotyledon weight exhibits an essentially linear response to stage of growth, unifoliate, trifoliate and total leaf weights exhibit a quadratic response with maximum values occurring at stage of growth B.

Significant response surfaces for root/leaf, root/stem and stem/leaf ratios were derived in experiment 2 (figure 3 : 5).

Both the root/leaf ratio and the stem/leaf ratio exhibited similar patterns of response to that of the root/shoot ratio for experiment 2. The root/stem ratio, however, was complex.

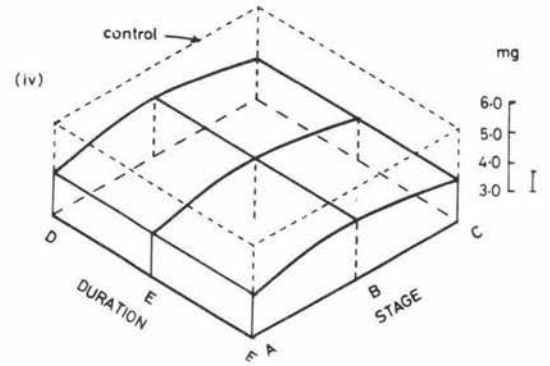
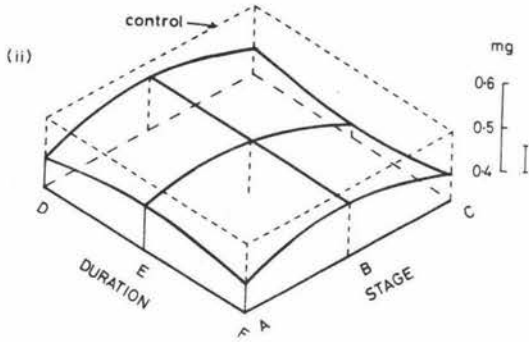
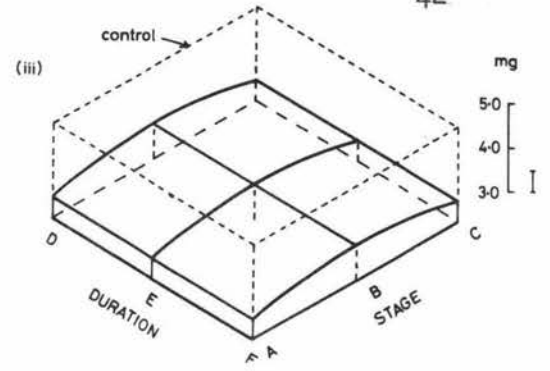
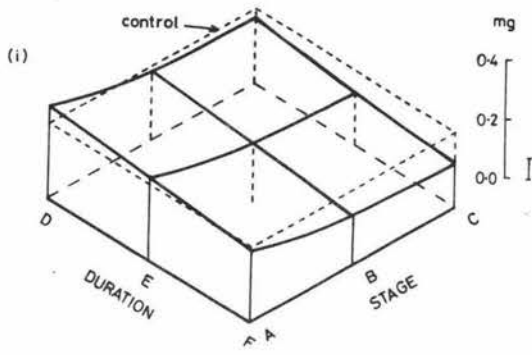


Figure 3 : 4

Response Surfaces.

- i. cotyledon weight
- ii. unifoliate leaf weight
- iii. trifoliate leaf weight
- iv. total leaf weight

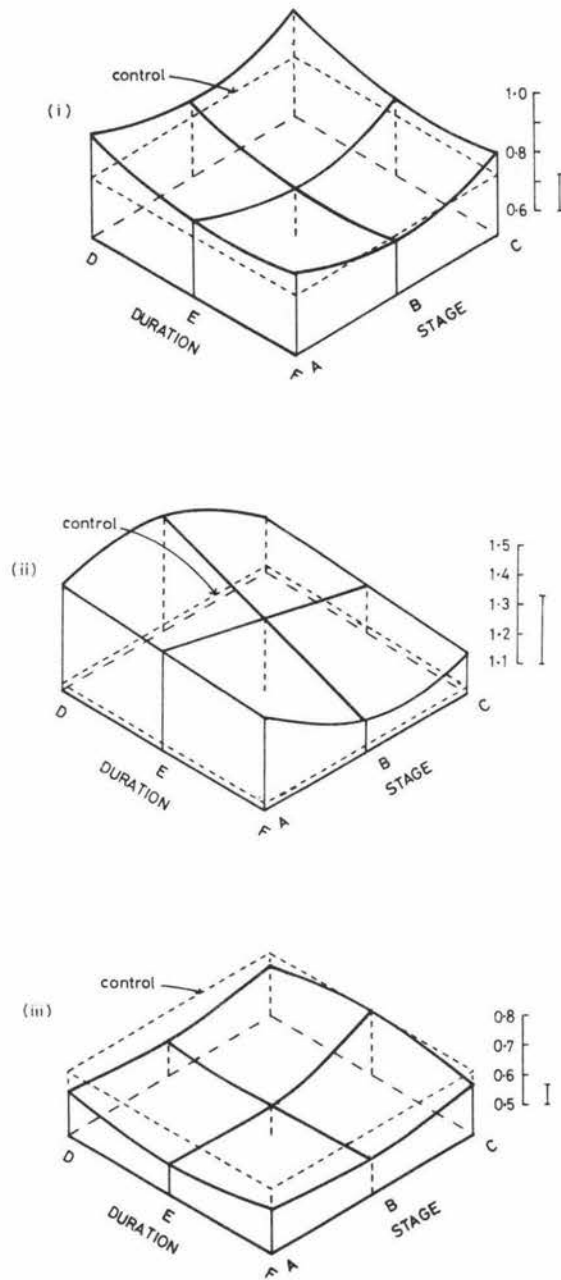


Figure 3 : 5

Response Surfaces.

- i. root/leaf ratio
- ii. root/stem ratio
- iii. stem/leaf ratio

Table 3:8 R.G.R.S (mg / mg / day) During and After Wind.
(Experiment 1)

<u>Stage</u>	<u>During Wind Application</u>			<u>After Wind Application</u>		
	<u>Total</u>	<u>Shoot</u>	<u>Root</u>	<u>Total</u>	<u>Shoot</u>	<u>Root</u>
A	0.172	0.208	0.193	0.130	0.113	0.145
B	0.186	0.185	0.288	0.116	0.118	0.112
C	0.067	0.063	0.081	0.150	0.154	0.121
	**	**	**	n.s.	n.s.	n.s.
Control	0.147	0.134	0.170	0.147	0.134	0.170
L.S.D. 5 %	0.069	0.046	0.076	0.034	0.050	0.050

Duration

D	0.139	0.191	0.212	0.132	0.121	0.139
E 0	0.136	0.133	0.169	0.146	0.138	0.137
F	0.151	0.131	0.180	0.117	0.127	0.102
	n.s.	*	n.s.	n.s.	n.s.	n.s.
Control	0.147	0.134	0.170	0.147	0.134	0.170
L.S.D. 5 %	0.069	0.046	0.076	0.034	0.050	0.050

Interaction

n.s. ** ** n.s. n.s. n.s.

* P = 0.05

** P = 0.01

n.s. not significant

3 : 3 Growth Analysis.

Details of the progress curve analyses and the R.G.R. analyses of variance and fitting data are given in appendices II and III respectively.

3 : 3 : 1 Experiment 1 (5.0 m/sec wind).

The R.G.R.s of the total plant, shoot and root at any point in time between days 6 and 28 of the experiment for the control plants were 0.147, 0.134, and 0.170 mg/mg/day respectively.

The R.G.R. main effects for the total plant, shoot and root both during and after the application of wind are given in table 3 : 8.

During the period of wind application, the total plant, shoot and root R.G.R.s were significantly smaller at stage of growth C than at stages of growth A and B. The R.G.R.s at stage of growth C were also significantly smaller than the respective control R.G.R.s. The total plant R.G.R.s at stages of growth A and B were not significantly different to control, but the shoot R.G.R.s at the same stages of growth were. The R.G.R. of the roots at stage of growth B was significantly greater than control. At stage of growth A, the shoot R.G.R. was significantly greater than the stage of growth C and control R.G.R.s. The R.G.R.s of the total plant, shoot, and root were not significantly affected by wind duration.

After the period of wind application, there were no significant main effect differences for any of three parameters measured. There were no significant differences from control either, with the exception of the root R.G.R. at stage of growth B and wind duration F.

3 : 3 : 2 Experiment 2 (7.5 m/sec wind).

The R.G.R.s of the total plant, shoot and root at any point in time between days 6 and 28 of the experiment for the control plants were 0.145, 0.133, and 0.160 mg/mg/day respectively. The relative leaf area growth rate (R.L.A.G.R.) for total leaf area over the same period of time for the control plants was 0.144 cm²/cm²/day.

Table 3:10 L.A.R. s (cm² / mg) During and After Wind.

<u>Stage</u>	<u>During Wind</u>	<u>After Wind</u>
A	0.200	0.208
B	0.198	0.194
C	0.208	0.200
	* *	* *
Control	0.210	0.210
L.S.D. 5 %	0.006	0.006
<u>Duration</u>		
D	0.204	0.207
E	0.200	0.198
F	0.202	0.197
	n.s.	* *
Control	0.210	0.210
L.S.D. 5 %	0.006	0.006
<u>Interaction</u>		
	* *	* *

* P = 0.05

* * P = 0.01

n.s. not significant

Table 3:11 N.A.R. s (mg / ca² / day) During and After Wind.

<u>Stage</u>	<u>During Wind</u>	<u>After Wind</u>
A	0.773	0.667
B	0.894	0.667
C	0.525	0.802
	* *	*
Control	0.690	0.690
L.S.D. 5 %	0.147	0.122
<u>Duration</u>		
D	0.692	0.674
E	0.787	0.671
F	0.713	0.791
	n.s.	n.s.
Control	0.690	0.690
L.S.D. 5 %	0.147	0.122
<u>Interaction</u>		
	n.s.	n.s.

* P = 0.05

* * P = 0.01

n.s. not significant

The R.G.R. main effects for the total plant, shoot and root both during and after the application of wind are given in table 3 : 9.

During the application of wind, the R.G.R. of the total plant was significantly smaller at stage of growth C than at stages of growth A,B, and the control R.G.R.s. Wind duration had no significant effect on the R.G.R. of the total plant. The R.G.R. of the shoot at stage of growth C was significantly smaller than at stages of growth A and B but was not significantly different to control. There were no significant wind duration shoot R.G.R. main effects but wind duration E was significantly greater than control. The R.G.R. of the root at stages of growth A and C were significantly smaller than at stage of growth B, but were not significantly different to control. Wind duration had no significant effect on the R.G.R. of the roots.

After the period of wind application, the R.G.R. of the total plant at stage of growth B was significantly less than at stage of growth C with one of the total plant R.G.R. main effects significantly different to control. Wind duration had no significant effect. The R.G.R. of the shoot was not significantly affected by either the stage of growth at which the wind had been applied or the duration of the wind. The R.G.R. of the roots at stages of growth A and B were significantly smaller than at stage of growth C, although not significantly different to the control R.G.R.

R.G.R. (0.145) and R.L.A.G.R. (0.144) were assumed to be equal in which case the L.A.R. for the control plants for days 6 to 28 of the experimental period was constant at $0.210 \text{ cm}^2/\text{day}$. N.A.R. was likewise constant through the defined experimental period at $0.690 \text{ mg}/\text{cm}^2$.

L.A.R. main effects are given in table 3 : 10. Although significant main effect differences from control were measured, the largest deviation from control was 0.013 or approximately 6%.

N.A.R. main effects both during and after wind application are given in table 3 : 11. During the application of wind, the N.A.R. at stage of growth B was significantly greater than at stage of C and also the control N.A.R.. N.A.R. at stage of growth C was sig -

Table 3:12 R.G.R.s (mg / mg / day) During and After Wind.
(Experiment 3)

<u>Stage</u>	<u>During Wind Application</u>			<u>After Wind Application</u>		
	<u>Total</u>	<u>Shoot</u>	<u>Root</u>	<u>Total</u>	<u>Shoot</u>	<u>Root</u>
A	0.071	0.089	0.057	0.132	0.116	0.163
B	0.142	0.146	0.134	0.102	0.092	0.121
C	0.072	0.049	0.115	0.180	0.182	0.178
	*	*	*	**	**	*
Control	0.123	0.112	0.146	0.123	0.112	0.146
L.S.D. 5 %	0.051	0.053	0.059	0.028	0.031	0.029

Duration

D	0.108	0.114	0.111	0.117	0.104	0.140
E	0.083	0.086	0.082	0.143	0.134	0.160
F	0.094	0.084	0.113	0.154	0.152	0.161
	n.s.	n.s.	n.s.	*	*	n.s.
Control	0.123	0.112	0.146	0.123	0.112	0.146
L.S.D. 5 %	0.051	0.053	0.059	0.028	0.031	0.029

Interaction

n.s. n.s. n.s. n.s. * *

* P = 0.05

** P = 0.01

n.s. not significant

nificantly smaller than control. Wind duration had no significant effect.

After the period of wind application, N.A.R. main effects were not significantly different to control. The N.A.R. at stage of growth C was significantly greater than N.A.R.s at stages of growth A and B. Wind duration had no significant effect.

3 : 3 : 3 Experiment 3 (10.0 m/sec wind).

The R.G.R.s of the total plant, shoot and root at any point in times between 6 and 28 days of the experiment for the control plants were 0.123, 0.112, and 0.146 mg/mg/day respectively.

The R.G.R. main effects for the total plant, shoot and root both during and after the application of wind are given in table 3 : 11.

Both the total plant and shoot R.G.R.s during the application of wind were significantly smaller at stages of growth A and C than at stage of growth B and the control R.G.R. Wind duration had no significant effect on either the total plant or shoot R.G.R.s. The R.G.R. of the roots at stage of growth A was significantly smaller than at stages of growth B, C, and the control R.G.R.s. The R.G.R. of the root at stage of growth B was significantly less than the control R.G.R. Wind duration had no significant effect.

The R.G.R.s of the total plant and root after the application of wind were significantly greater at stages of growth A and C than at stage of growth B. Only the R.G.R.s at stage of growth C were significantly different to control. Wind duration had no significant effect on the R.G.R. of the root but the R.G.R. of the total plant at wind duration D was significantly smaller than at wind duration F. The R.G.R. of the shoot was significantly greater at stage of growth C than at stages of growth A, B, and the control R.G.R.s. The R.G.R.s of the shoot at wind durations D and F were also significantly different to control.

Table 3 : 13 R.G.R.s (mg/mg/day) During and After Wind
At three Wind Speeds.

<u>Wind</u>	<u>During Wind</u>			<u>After Wind</u>		
	<u>Total</u>	<u>Shoot</u>	<u>Root</u>	<u>Total</u>	<u>Shoot</u>	<u>Root</u>
5.0	0.142	0.152	0.187	0.131	0.129	0.126
7.5	0.147	0.150	0.168	0.142	0.129	0.167
10.0	0.113	0.104	0.115	0.164	0.155	0.174
	*	**	**	*	*	*
Control	0.146	0.133	0.165	0.146	0.133	0.165
L.S.D. 5 %	0.031	0.025	0.035	0.017	0.021	0.022
<u>Stage</u>						
A	0.136	0.152	0.137	0.140	0.125	0.163
B	0.176	0.173	0.219	0.121	0.117	0.128
C	0.088	0.081	0.115	0.175	0.170	0.175
	**	**	**	**	**	**
Control	0.146	0.133	0.165	0.146	0.133	0.165
L.S.D. 5 %	0.031	0.025	0.035	0.017	0.021	0.022
<u>Duration</u>						
D	0.137	0.153	0.173	0.136	0.124	0.153
E	0.130	0.131	0.144	0.149	0.139	0.157
F	0.134	0.122	0.153	0.152	0.150	0.157
	n.s.	*	n.s.	n.s.	n.s.	n.s.
Control	0.146	0.133	0.165	0.146	0.133	0.165
L.S.D. 5 %	0.031	0.025	0.035	0.017	0.021	0.022
<u>Interaction</u>						
	W x S ^t	W x S ^{**}	W x S ^{**}	W x S [*]	W x S [*]	W x S ^t
	-	S x D ^{**}	S x D ^{**}	W x D [*]	-	W x D [*]

* P = 0.05, ** P = 0.01, ^tP = 0.10, n.s. not significant.

Table 3 : 14 Combined R.G.R. Wind Speed by Stage of Growth
Interaction Data.

Total Plant Stage	<u>During Wind</u>			<u>After Wind</u>		
	A	B	C	A	B	C
<u>Wind</u>						
5.0 m/sec	0.171	0.186	0.089	0.129	0.116	0.150
7.5 m / sec	0.150	0.176	0.110	0.136	0.128	0.162
10.0 m / sec	0.083	0.168	0.102	0.156	0.121	0.214
<u>Shoot</u>						
<u>Wind</u>						
5.0 m / sec	0.208	0.185	0.063	0.113	0.118	0.154
7.5 m / sec	0.149	0.175	0.127	0.123	0.124	0.141
10.0 m / sec	0.098	0.160	0.054	0.138	0.110	0.216
<u>Root</u>						
<u>Wind</u>						
5.0 m / sec	0.193	0.288	0.081	0.144	0.122	0.121
7.5 m / sec	0.153	0.217	0.135	0.162	0.135	0.204
10.0 m / sec	0.064	0.152	0.130	0.184	0.137	0.201

3 : 3 : 4 Combined Relative Growth Rates.

The R.G.R. main effects for wind speed, stage of growth, and wind duration both during and after the application of wind are given in table 3 : 13.

During the period of wind application, the 10.0 m/sec wind speed significantly reduced the total plant, shoot, and root R.G.R.s compared to the other two wind speeds and control. The total plant, shoot, and root R.G.R.s at stage of growth C were significantly smaller than at state of growth B and also control in the case of the shoot and root R.G.R.s. Only the shoot R.G.R.s were significantly affected by wind duration. Significant negative interactions were measured in the shoot and root R.G.R. analyses.

The R.G.R.s of the total plant and shoot after the period of wind application were significantly greater at stage of growth C than at stages of growth A and B. The R.G.R. of the root at stages of growth B and C were significantly greater than at stage of growth A. The total plant and root R.G.R.s at stages of growth A and C were significantly greater than at stage of growth B. The shoot R.G.R. at stage of growth C was significantly greater than at stages of growth A and B. Wind duration had no significant effect on the R.G.R.s of the total plant, shoot or root.

3 : 3 : 5 Response Surfaces.

Significant response surfaces were derived for total plant R.G.R.s in all three experiments during the application of wind but after the application of wind in experiments 2 and 3 only (figure 3 : 6).

The total plant R.G.R. patterns of response during wind application were essentially quadratic with respect to stage of growth with maximums at stage of growth B. The total plant R.G.R. patterns of response after wind application (experiments 2 & 3 only) were again quadratic with respect to stage of growth but with minimums at stage of growth B.

Significant response surfaces were derived for shoot R.G.R.s

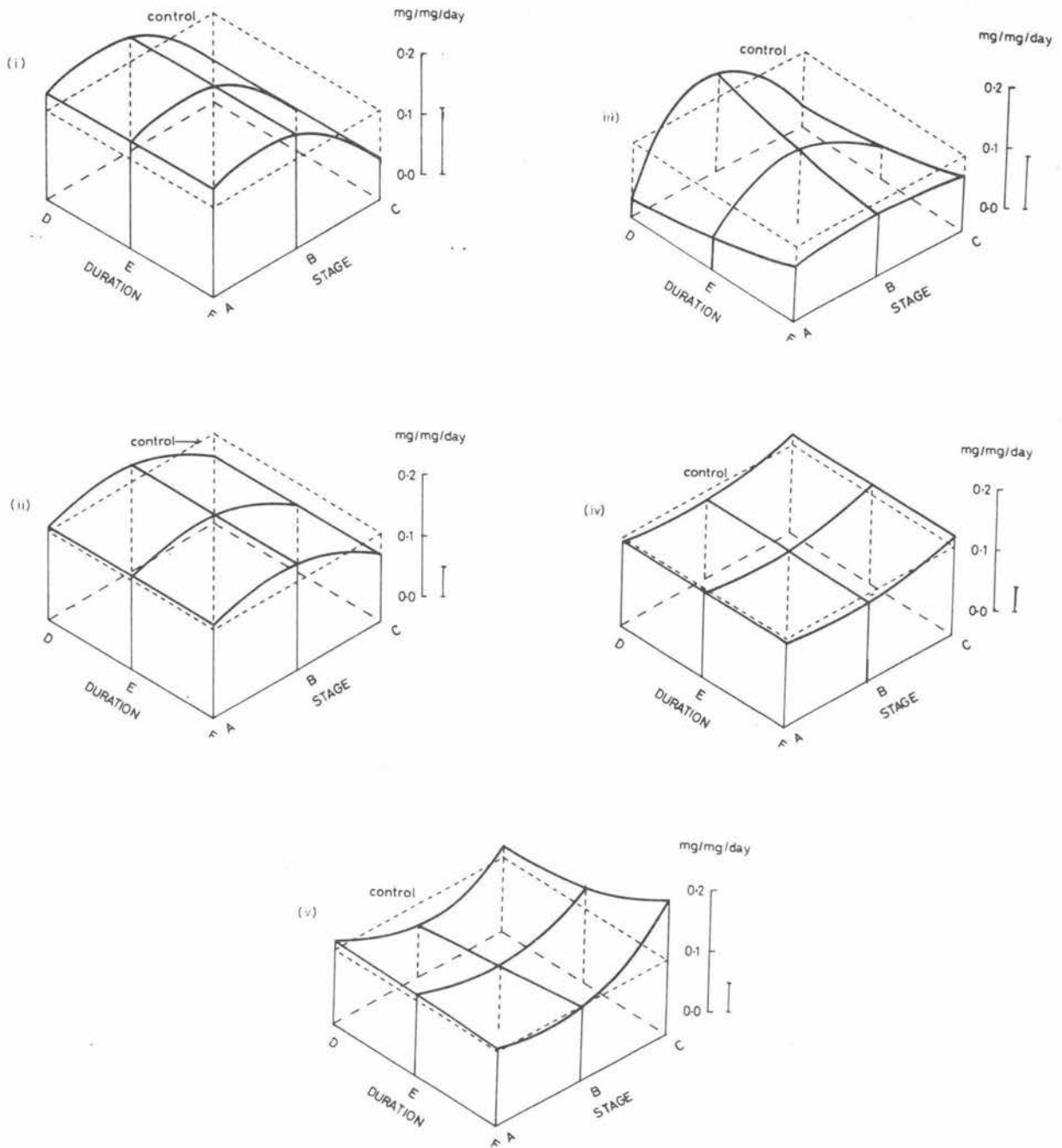


Figure 3 : 6

Response Surfaces.

- i. total plant R.G.R. during wind (experiment 1)
- ii. total plant R.G.R. during wind (experiment 2)
- iii. total plant R.G.R. during wind (experiment 3)
- iv. total plant R.G.R. after wind (experiment 2)
- v. total plant R.G.R. after wind (experiment 3)

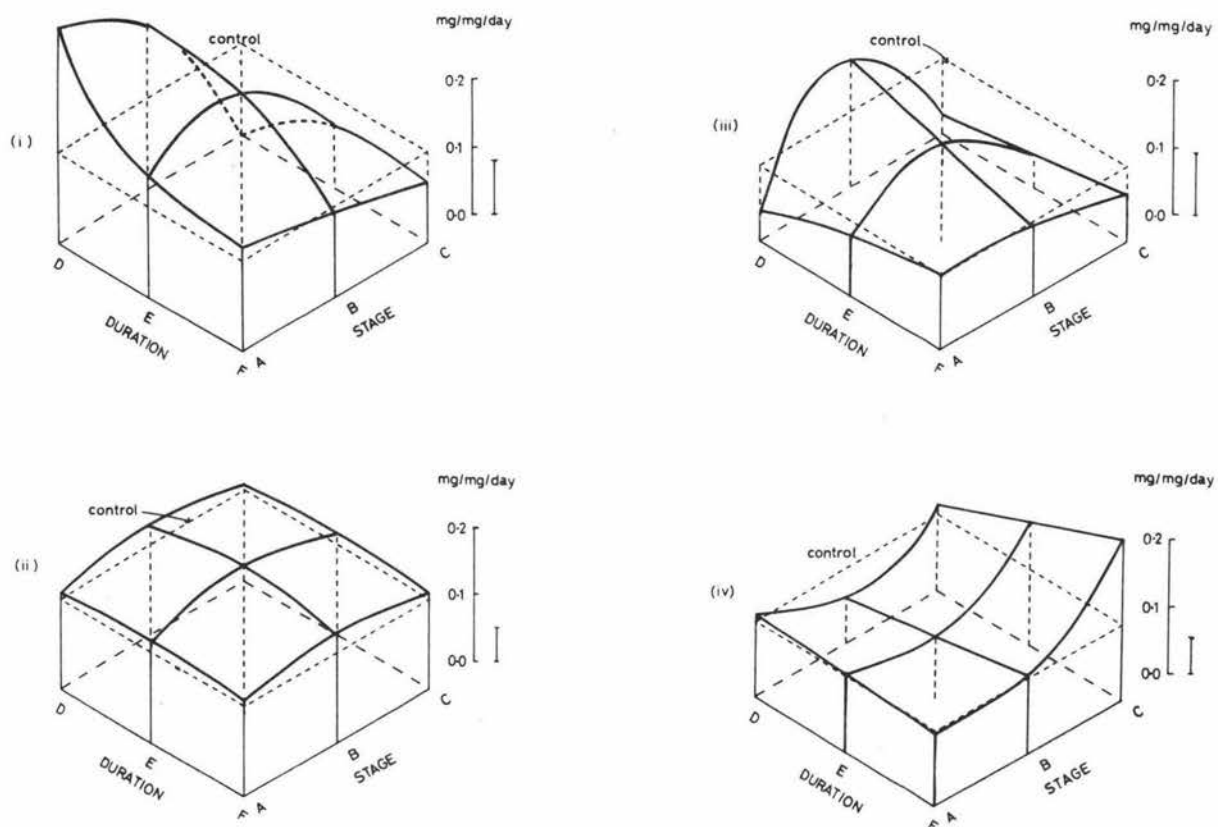


Figure 3 : 7

Response Surfaces.

- i. shoot R.G.R. during wind (experiment 1)
- ii. shoot R.G.R. during wind (experiment 2)
- iii. shoot R.G.R. during wind (experiment 3)
- iv. shoot R.G.R. after wind (experiment 3)

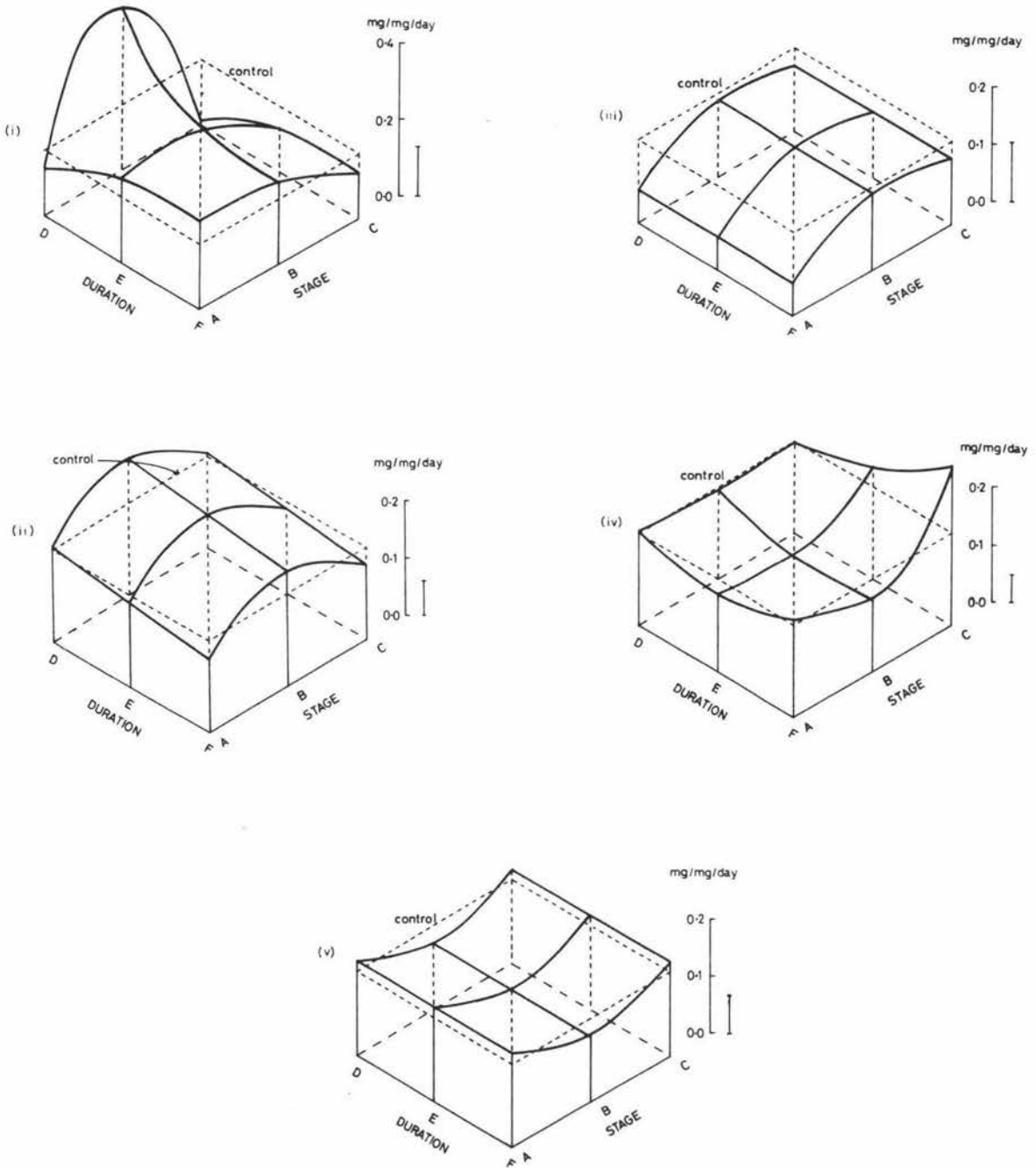


Figure 3 : 8

Response Surfaces.

- i. root R.G.R. during wind (experiment 1)
- ii. root R.G.R. during wind (experiment 2)
- iii. root R.G.R. during wind (experiment 3)
- iv. root R.G.R. after wind (experiment 2)
- v. root R.G.R. after wind (experiment 3)

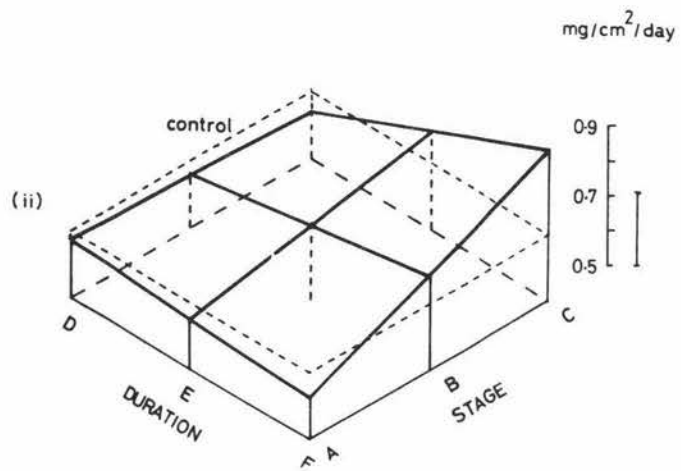
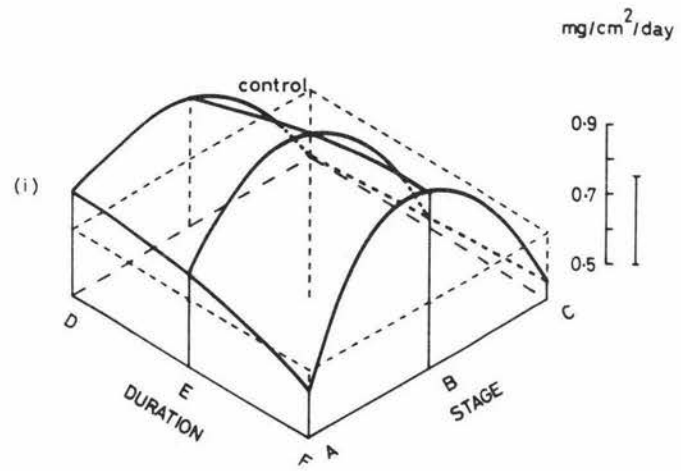


Figure 3 : 9

Response Surfaces.

- i. N.A.R. during wind
- ii. N.A.R. after wind

in all three experiments during the application of wind but after the application of wind in experiment 3 only (figure 3 : 7).

The shoot R.G.R. patterns of response in experiments 1 and 3 during the application of wind were irregular compared to the pattern obtained in experiment 2 but all three were quadratic with respect to stage of growth. Shoot R.G.R. after wind application (experiment 3) was also quadratic with respect to stage of growth but in the opposite direction.

Significant response surfaces were derived for root R.G.R.s in all three experiments during the application of wind and after wind application in experiments 2 and 3 (figure 3 : 8).

Essentially quadratic patterns of response with respect to stage of growth were obtained in all three experiments with maximum values at stage of growth B during wind application. Quadratic patterns of response with respect to stage of growth were obtained in experiments 2 and 3 after wind application but with minimum values at stage of growth B.

Significant response surfaces for N.A.R. both during and after the application of wind were derived in experiment 2 (figure 3 : 9).

3 : 4 Relative Water Content (Experiment 2).

R.W.C. main effect values at the three stages of growth and at the three durations are given in tables 3 : 15, 3 : 16, and 3 : 17.

At all stages of growth, the most recently formed tissue had significantly lower R.W.C. values than the older tissues. The R.W.C.s during wind application were, in general, significantly lower than both the control and after wind treatments. At all stages of growth, the R.W.C. values after wind treatment were higher (significantly so on three occasions) than the control values. Significant negative interactions between type of plant tissue and wind treatment occurred in three analyses.

Table 3:15

Relative Water Content (%).

At Cotyledon Stage of Growth (A).

Wind Duration	D	E	F	F + 2
<u>Treatment</u>				
Cotyledons	88.73	90.12	91.59	95.51
Unifoliolate Leaf	-	79.42	84.80	90.78
		**	**	**
L.S.D. 5 %	-	1.98	1.74	1.65
During Wind	84.04	80.41	86.37	-
After Wind	-	87.93	89.42	92.61
Control	88.73	85.97	88.87	93.67
	n.s.	**	*	n.s.
L.S.D. 5 %		2.42	2.43	1.65
Interaction		**	n.s.	n.s.

Table 3:16

Relative Water Content (%)

At Unifoliolate Stage of Growth (B).

Wind Duration	D	E	F	F + 2
<u>Treatment</u>				
Cotyledons	90.04	95.97	94.14	96.05
Unifoliolate Leaf	86.61	89.97	90.19	93.95
Trifoliolate Leaf(1)	80.82	81.09	83.10	89.79
	**	**	**	**
L.S.D. 5 %	3.52	1.81	1.11	1.45
During Wind	82.74	86.02	87.85	-
After Wind	-	91.01	90.95	94.17
Control	88.91	90.01	88.63	92.37
	**	**	**	**
L.S.D. 5 %	2.87	1.81	1.11	1.19
Interaction	n.s.	*	*	n.s.

Table 3:17

Relative Water Content (%)
At Trifoliate Stage of Growth (C).

<u>Wind Duration</u>	D	E	F	F + 2
<u>Treatment</u>				
Unifoliate Leaf	94.56	95.39	93.96	95.67
Trifoliate Leaf(1)	90.77	92.28	92.51	94.07
Trifoliate Leaf(2)	84.78	88.23	85.30	90.63
	* *	* *	* *	*
L.S.D. 5 %	2.16	1.11	1.41	1.19
During Wind	89.48	88.67	86.15	-
After Wind	-	94.09	93.80	93.69
Control	90.54	93.15	91.83	93.23
	n.s.	* *	* *	n.s.
L.S.D. 5 %	1.77	1.11	1.41	0.97
Interaction	n.s.	n.s.	n.s.	n.s.

3 : 5 Transpiration Rates (Experiment 2).

Mean transpiration rates and standard errors of the mean at the three stages of growth at the three wind durations are given in table 3 : 18. In general, there were no big differences between the wind treatments and control. The exception to this generalisation was wind treatment ' E + 2 ' at stage of growth A.

3 : 6 Stomatal Aperture (Experiment 2).

The frequency of occurrence of open stomata at the three stages of growth are given in table 3 : 19. On all occasions, the frequency of occurrence of open stomata were higher on the control plant leaves than on the wind treated plant leaves. On the two occasions that stomatal opening were measured after the wind treatment had ceased, the frequency of occurrence of open stomata was similar to that of the control plants.

Table 3:18 Transpiration (mg Water / mg shoot Tissue / day¹).

Stage of Growth Cotyledons Unifoliolate Leaf Trifoliolate Leaves.

Wind Treatment

' D '	92.16 ± 11.32	51.24 ± 2.55	44.76 ± 6.39
Control	83.85 ± 7.48	42.43 ± 4.07	53.64 ± 4.78
' E '	48.72 ± 5.87	29.28 ± 0.34	34.20 ± 3.95
' D + 2 '		22.32 ± 0.93	39.10 ± 3.70
Control	45.60 ± 3.37	19.56 ± 1.89	32.28 ± 5.73
' F '	44.48 ± 1.29	39.72 ± 1.61	39.30 ± 4.37
' E + 2 '	94.40 ± 13.33	32.40 ± 3.29	
Control	33.68 ± 2.14	33.12 ± 3.57	45.12 ± 2.16
' F + 2 '		44.76 ± 4.63	
Control		53.16 ± 1.81	

(1/ day of 8 hours.)

Table 3:19 Frequency of Occurrence of Open Stomata.

Stage of Growth (A).

<u>Wind Treatment</u>	<u>Control</u>	<u>'D'</u>	<u>Control</u>	<u>'E'</u>
<u>Type of Leaf</u>				
Cotyledons	0.94	0.44	0.61	0.59
Unifoliate Leaf	-	-	0.92	0.46

Stage of Growth (B).

<u>Wind Treatment</u>	<u>Control</u>	<u>'D'</u>	<u>Control</u>	<u>'D+2'</u>	<u>'E'</u>	<u>Control</u>	<u>'F'</u>
<u>Type of Leaf</u>							
Cotyledons	0.94	0.42	0.93	0.89	0.91	0.93	0.56
Unifoliate Leaf	0.59	0.15	0.61	0.67	0.20	0.86	0.04
Trifoliate Leaves	0.77	0.05	0.77	1.00	0.30	0.95	0.00

Stage of Growth (C).

<u>Wind Treatment</u>	<u>Control</u>	<u>'D'</u>	<u>Control</u>	<u>'D+2'</u>	<u>E</u>
<u>Type of Leaf</u>					
Unifoliate Leaf	0.76	0.54	0.96	1.00	0.50
Trifoliate Leaves	1.00	0.09	0.96	1.00	0.33

4 : 1 Introduction.

It will be apparent from the review of pertinent literature in chapter 1 that wind effects, with the exception of mechanical damage, are primarily water stress effects on plant growth and metabolism. In an attempt to rationalise this discussion, the ancillary R.W.C., transpiration, and stomatal aperture data will be discussed prior to the main body of experimental results.

All the data with the exception of the transpiration and stomatal aperture data were statistically analysed. With the exception of these two sets of data and the R.W.C. data, response surfaces are used as the basis of discussion rather than tabular material. Response surfaces have been used because they provide a means of smoothing erratic data points and also because they identify significant trends rather than significant values. Traditionally, response surface methodology has been used in industrial investigations (Davies et al 1956, Lynch 1966) as a means of identifying points of optimum response in multifactor situations. In most biological and in particular, agronomic investigations, significant trends are rarely identified and used as the basis of discussion. Significant trends are likely to be of considerable value in most biological situations and yet response surface methodology is rarely used. Possible reasons for this include the greater variance present in most biological as compared to industrial situations and the apparent non-requirement of biological optimum response point identification.

The findings of the three experiments must be interpreted in the light of the stresses that were applied. Daily wind cycles of 8 hours for 2, 4, or 6 days at three distinct stages of growth were applied which is in contrast to the continuous winds used by Whitehead and other workers. In addition to the wind stress, a varying and uncontrolled stress in the form of radiation load on the plants was exerted. The effects measured in these experiments are essentially a compound of the radiation load on the plant, the prevailing air temperature and humidity and wind velocity. The water retention characteristics of the potting medium determined the amount of water taken up by the roots and these were not measured. But, the sub-irrigation practice used insured as near an optimum supply as the potting medium allowed at all times.

The detailed sectioning out of the plants, R.W.C., transpiration and stomatal aperture data collected in experiment 2 was an attempt to define more closely how the plant reacted to what, for the purposes of this thesis, is termed 'wind stress' but which is effectively, the compound stress explained earlier. It is considered that the stress effects measured at 7.5 m/sec reflect to a greater or lesser extent, the stresses at wind speeds of 10.0 and 5.0 m/sec respectively.

4 : 2 Water Relations (Experiment 2).

Criticism could possibly be levelled at the method of analysis used for the R.W.C. data given in tables 3:15, 3:16, and 3:17. It was considered that the main effect analysis would provide an indication of the water status of the whole plant under the various wind treatments, i.e. during wind, after wind, and control. Any differential effect of wind stress on component leaves would be indicated by a significant interaction term. Such interactions were measured on three occasions. This technique did not provide an absolute measurement of the water status of the whole plant because to achieve this each component used in the analysis would have to comprise an equal dry weight (or leaf area) proportion. This was not achieved and so the R.W.C. values presented cannot be readily extrapolated.

At the most, a water stress of 5 to 8 percentage points was induced by the application of wind. Hsiao (1973) loosely quantified water stress for the purposes of his review as follows ;

1. mild stress... water potential lowered by several bar or R.W.C. by 8 to 10 percentage points ,
2. moderate stress... water potential lowered by more than a few bar but less than 12 to 15 bar or R.W.C. lowered by 10 to 20 percentage points,
3. severe stress... water potential lowered by more than 15 bar or R.W.C. lowered by more than 20 percentage points.

If Hsiao's (1973) classification is adhered to, then the stress applied by the wind speed of 7.5 m/sec in experiment 2 would be mild. However, Hsiao (1973) does not distinguish between physiologically young and old tissue. Millar *et al* (1968) derived leaf moisture characteristic curves (R.W.C. versus leaf water potential) for barley

leaves. They found that for physiologically young leaves that R.W.C. values of between 90 and 100 % accounted for a leaf water potential range of approximately 0 to - 20 bar. Leaf moisture characteristic curves vary considerably between species and with stages of growth (Hsiao 1973) but it is possible in view of the findings of Millar et al (1968) that a small R.W.C. range such as that found in this experiment could account for a large range of water potential in physiologically young leaves. Ehlig & Gardner (1965) found that for Lotus corniculatus L. , the osmotic potential of mature unshaded leaves decreased linearly with decreases in the R.W.C. of the leaf. In this experiment the R.W.C. values two days after the cessation of wind treatment were higher than control (tables 3:15, 3:16, 3:17) and on the basis of the linear relationship between osmotic potential and R.W.C., it is probably reasonable to suggest that osmotic potentials were also higher. Boyer (pers. comm.) has suggested that in young tissues, osmotic compensation allows cell expansion to continue when leaf water potentials fall with developing water stress. However, hastened senescence (Gates 1968) would probably produce a similar effect.

On the occasions that there were significant interactions, the youngest tissue was desiccated the most and the oldest, the least. It is considered that this was a function of leaf position, the youngest tissue being the most exposed to the wind. At the trifoliate stage of growth the plant appeared to have a greater ability to redistribute water as evidenced by the lack of negative interactions i.e. the youngest tissue was not as severely desiccated as at the cotyledon and unifoliate stages of growth. Indirect evidence for this mechanism which is perhaps the hastened senescence of Gates (1968) can be drawn from table 3:2. There were fewer cotyledons and unifoliate leaves at the trifoliate stage of growth. However, this effect could possibly also be explained by the fact that at the trifoliate stage of growth there was a greater bulk of tissue present in the tunnel which probably meant that proportionally, there was a smaller area exposed to the wind.

The technique used for measuring transpiration did not appear to limit plant growth even at the trifoliate stage of growth but it is possible in view of the root system that had developed by this time that the plants in these pots were root bound. The warm vaseline used to seal the plants in the containers had no visible injurious effect on the plant stem or apparently the xylem tissue as evidenced by the continued trans -

piration. The general absence of big differences between the wind treated and control plants transpiration rates suggests two interesting alternatives ;

1. the stomata did not close because the stress imposed was insufficient to cause closure,
2. the stomata did close in the wind treated plants but cuticular transpiration was high.

Hsiao (1973) commented that the threshold water potential value for stomatal closure varied between - 7 and - 9 bar for tomato to - 12 to - 16 bar for grapes. Boyer (1973b) observed that the threshold value for partial closure of corn stomata was - 3.5 bar and Millar et al (1968) considered that the relative transpiration data for barley in their experiments indicated closure of the stomata at - 22 bar. Thus it is possible that if only a mild stress was imposed, that the stomata may have remained open.

The technique of stomatal aperture assessment used in this experiment was successful up to a point. It was necessary to interpret the shape of the guard cells to determine whether or not they were open. Debris on the impression from the leaf surface often made assessment difficult. However, the general effects of wind stress on stomatal aperture were determined to the point that differences between partial to full closure and partial to fully open were measurable. Thus the stomatal aperture data would suggest that cuticular transpiration was high during the application of wind. While, energy budget considerations (Gates 1968) could account for the differences in transpiration rates at the various measurement times, it is unlikely that such considerations would account for the lack of differences between the wind treated and control plants because the main effect of wind which is to reduce boundary layer resistance reaches its maximum effectiveness at 0.5 m/sec (Gates 1968). Even if the stomatal data indicates only partial closure, transpiration rates of the treated plants should have been substantially reduced. The fact that transpiration rates were not reduced indicates cuticular transpiration. The partial closure of the stomata of the wind treated plants also suggests that the water stress imposed upon the plants was in the vicinity of moderate stress as defined by Hsiao (1973).

4 : 3 Final Harvest.

The effect of the three wind speeds on plant growth , as expressed in dry weight accumulation, can be presented as a percentage increase or decrease relative to control. The patterns of response in experiments 1 and 2 were similar and the point of maximum wind effect occurred during the trifoliate stage of growth. In experiment 3, the pattern of response was different with the maximum effect of wind occurring during the unifoliate stage of growth. No reason for the pattern of response observed in experiment 3 can be advanced.

<u>Table 4 : 1</u>	<u>Percentage Reductions in Dry Weight.</u>		
	<u>Experiment 1</u>	<u>Experiment 2</u>	<u>Experiment 3</u>
Total Plant	- 22	- 24	- 5 (- 27)
Shoot	- 27	- 29	- 17 (- 31)
Root	- 14	- 18	+ 25 (- 24)

(Figures in brackets are for the unifoliate stage of growth.)

Changes in percentage dry weights for the total plant, shoot, and root for the three experiments are depicted in table 4:1. While the results from experiment 3 do not seem to fit the pattern of experiments 1 and 2, it is apparent that the maximum effect of wind is a reduction in dry weight of the order of 22 - 27 %, 27 - 31 %, and 14 - 24 % for the total plant , shoot and root respectively.

Table 4 : 2 Percentage Reductions in Leaf Area and Dry Weight.

	<u>Leaf Area</u>	<u>Dry Weight</u>
Cotyledons	- 30	- 40
Unifoliate Leaf	- 38	- 22
Trifoliate Leaf	- 15	- 29
Total Leaf	- 15	- 29

Percentage reductions in leaf area and dry weight for the dissected plants (experiment 2) are given in table 4:2. Whitehead (1965a) reported a reduction in leaf area and stem internode length for maize and sunflower plants under continuous wind . He also reported the same changes in sunflower in response to water stress. In this experiment, the reduction in leaf area and dry weight of the cotyledons and unifoliate leaves is

almost certainly due to the reductions in numbers of both (figure 3:3). The number of trifoliolate leaves did not decrease and hence the decrease in area can be attributed to a reduction in cell size or numbers. The greater percentage reduction in trifoliolate leaf weight than leaf area would seem to suggest leaf structural changes and perhaps hastened senescence.

The root/shoot and other plant weight ratios of experiment 2 indicate the plant response to wind stress. The response surfaces of the root/shoot ratios (figure 3:2) in all three experiments depicted essentially similar patterns of response with higher values at the cotyledon and trifoliolate stages of growth. Whitehead (1965a) has reported higher root/shoot ratios for maize and sunflower plants under wind stress and sunflower plants under water stress. Davidson (1969) and Engin & Sprent (1973) have reported increased root/shoot ratios for white clover plants under water stress. The nil effect of wind stress on root/shoot ratios particularly in experiments 2 and 3 at the unifoliolate stage of growth is of considerable interest and will be discussed in a later section together with the other plant weight ratios.

4 : 4 Growth Analysis.

A full discussion of the growth analysis techniques used is not warranted. A mixture of classical and modern growth analysis techniques were used. The significant exponential progress curves for the control plants enabled the derivation of R.G.R.s which were instantaneously applicable at any time during the period of measurement. The R.G.R.s of the wind treated plants were however, mean values.

One problem encountered with the techniques used was that mean R.G.R.s over different periods of time were compared. This was apparently not serious during the period of wind application where the comparisons were at 2, 4, and 6 days, but during the period after the application of wind had ceased, the comparisons ranged from 2 to 20 days. Despite this, the coefficient of variations for the periods after wind application were in almost all instances lower than during wind application. It is considered that day to day variations in radiation load on the plants contributed significantly to the high variation encountered. Significance was achieved in many instances despite this high variation.

The adjustment of the R.G.R. data from experiment 3 to enable the combination of the data from all three experiments is considered to be justified. The control plant R.G.R.s over this period were exponential and hence a simple arithmetic transformation was all that was required. The lower R.G.R.s encountered in experiment 3 are considered to be attributable to lower net radiation levels and that the transformation merely reflects this.

The total plant, shoot, and root R.G.R. response surfaces for all three experiments during the application of wind depict essentially similar patterns of response with an apparent stimulatory effect on growth at the unifoliate stage. Examination of the wind speed by stage of growth interactions for the combined R.G.R. data (table 3:14) reveals that during wind application at the cotyledon and unifoliate stages of growth, the total plant, shoot and root R.G.R.s decrease with increasing wind speed. At the trifoliate stage of growth there is a distinct stage of growth effect with a maximum occurring at a wind speed of 7.5 m/sec. In view of other published work (Wadsworth 1959) a linear decrease in R.G.R. with wind speed would be expected at the trifoliate stage of growth. The significant stage of growth by wind duration interactions (combined R.G.R. data) for the shoot and root R.G.R.s showed that the lowest R.G.R.s at the trifoliate stage of growth occurred during the first two days of wind application. Examination of the thermohydrograph records for experiment 1 (5.0 m/sec) revealed that these days were very hot (maximum approximately 30 C) and it is considered that the low R.G.R.s at the trifoliate stage of growth in this experiment (1) are attributable to the severe stresses placed upon these plants. Hence under conditions of constant radiation loading a linear decrease in R.G.R. with increasing wind speed can probably be expected.

There is a marked quadratic stage of growth effect in the combined data with a maximum occurring at the unifoliate stage of growth. This is similar to the patterns depicted in the response surfaces of the individual experiments (figures 3 : 6, 3 : 7, 3 : 8). Wadsworth (1959) applied winds of up to 12 m/sec to rape plants whose first leaves were approximately 1 cm long. He found that R.G.R. increased with wind speed when the plants were less than 1 cm tall, that there was an optimum wind speed for plant growth when the plants were between 1 and 4 cm tall, and that the R.G.R. of plants taller than 4 cm decreased with increasing wind speed. Somewhat similar results have been obtained in this series

of experiments with growth stimulation at the unifoliate stage and growth suppression at the trifoliate stage. However, no optimum wind speed for plant growth was apparent. The R.G.R. response surfaces during wind application (figures 3:6, 3:7, 3:8) with the exception of those derived for experiment 3, suggest that the plant is better able to withstand wind stress at the cotyledon stage of growth than at the trifoliate stage of growth. The experiment 3 R.G.R. response surfaces indicate considerably reduced growth at the cotyledon stage of growth. The nature of the wind profile in the tunnel was not determined but it was considered to be logarithmic in which case wind speed would increase with height above the pots. This means that plants exposed to wind at the unifoliate and trifoliate stages of growth would be exposed to higher wind velocities than plants exposed at the cotyledon stage of growth. Hence, in actual fact, the cotyledon stage of growth is probably quite sensitive to wind stress, more so than the unifoliate and trifoliate stages of growth.

After wind application, the response surfaces which were significant (experiments 2 and 3) depict in general the reverse of the pattern that occurred during wind application. Where the R.G.R.s had been depressed during the application of wind, they increased in the after wind period such that in general, the highest R.G.R.s occurred in plants that had been exposed to a wind of 10.0 m/sec. Plants that had been exposed to wind at the unifoliate stage of growth had lower R.G.R.s than plants exposed at the cotyledon or trifoliate stages of growth. Gates (1968) reported that the R.G.R.s of tomato plants were increased above the level of control after the alleviation of moisture stress. He used relatively mature plants and only the plants exposed to wind at the trifoliate stage of growth could be reasonably compared. Similar results were obtained.

It was necessary with the method of analysis used to assume that the L.A.R.s did not vary significantly in order that the N.A.R.s for the during and after wind periods to be derived. However, they did vary significantly although the largest variation was only 6% of the control value. The coefficients of variation were very small (0.4%) and it was decided that the errors involved in assuming L.A.R. to be constant were well below the levels of other measurement errors. Wadsworth (1959) was obliged to make a similar assumption. The N.A.R. response surfaces during and after wind application were essentially similar to the R.G.R. response surfaces. Wadsworth (1959) also found that N.A.R. responded in a similar manner to R.G.R..

4 : 5 Synthesis.

Increased root/shoot ratios in response to stress are reported frequently in the literature (sections 1 : 2, 1 : 4). The high root/shoot, root/leaf, root/stem and low stem/leaf ratios at the cotyledon stage of growth together with the linear reduction in R.G.R. with wind speed suggest that the white clover plant is sensitive to wind stress at this stage. At the unifoliate stage of growth, however, the root/shoot and root/leaf ratios were the same as control which perhaps suggests that wind stress has no effect on the plant at this stage. The root/stem and stem/leaf ratios were higher and lower than control respectively at this stage. N.A.R.s and R.G.R.s were greater than the control rates at this time despite R.W.C. and stomatal aperture data which were suggestive of the existence of a moderate water stress. It is possible that the cotyledons were relatively unstressed (the cotyledons had the highest R.W.C. levels and frequency of open stomata) and were able to produce sufficient photosynthate to support the elevated R.G.R.s measured. Such an effect would allow dry weight accumulation to continue with the major effect of moisture stress being reduced cell extension. At the trifoliate stage of growth the root/shoot, root/leaf and root/stem ratios are all higher than control. These ratios are again suggestive of stress which is supported by the lower N.A.R.s and R.G.R.s, R.W.C. and stomatal aperture data. The cotyledons and unifoliate leaves although less stressed than the trifoliate leaves are probably unable to provide sufficient photosynthate for the support of R.G.R.s equivalent to control and hence the R.G.R.s are lower than control.

It is considered that the changes in root/shoot ratios measured were incurred during the periods of wind stress and maintained during the period after wind. The shoot and root R.G.R.s after wind application appear to be more or less proportional which would support this contention.

4 : 6 Relevance of Results to Field Situations.

The relevance of results obtained in artificial environments to field situations is limited because of the complex of factors which interact in the field and which are controlled in the laboratory. However, general principles obtained in the laboratory can often be applied in the field.

McWilliam *et al* (1968) reported that the radicles of oversown subterranean clover seedlings are susceptible to dessication and that losses can be considerable at this stage. Campbell (1973) concluded that moisture supply by controlling the growth and survival of seeds and seedlings, and by modifying the environment at the soil surface, had a commanding influence on the success or failure of surface sowing. It was considered, prior to the commencement of this investigation (section 2 : 1) that wind stress could influence the growth of white clover seedlings through moisture stress. This has been established under relatively ideal conditions as far as plant available water is concerned. In view of the above reported work, it is obvious that in the field, plant fatality is likely to be high in many situations before the cotyledons are fully expanded which was the starting point of this investigation.

If a moisture stress is applied to a white clover seedling after the appearance of the first trifoliate leaf, then a reduction in N.A.R. and therefore R.G.R. can be expected. At this stage of growth even though the stomata may be closed, the rate of transpiration does not diminish which means that the moisture stress is increased and more water is withdrawn from the soil. If rain is not forthcoming, then the plant could die from dessication. Such a situation is possible if clover is oversown onto a bare face. However, if clover is oversown into established pasture, then the sheltering effects of the pasture will almost certainly enhance the chances of the seedlings surviving hot dry winds. Although confirmation that cuticular transpiration does occur in white clover seedlings is required, it is apparent that its inability to control water loss in wind is a severe limitation to its ability to survive and establish in difficult situations. Mechanical injury does not seem likely with winds up to 10.0 m/sec.

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Appendix IAnalyses of Variance For Final Harvest Data.

In the tables to follow, the letters ' S ' and ' D ' refer to stage of growth and duration of wind respectively while the sub - scripts ' L ' and ' Q ' refer to the linear and quadratic components of the source of variance. The lack of fit term bracketed in the individual tables is comprised of all the terms in the analysis that are not significant at the P = 0.10 level. The fitted surface equation coefficients are applicable only in conjunction with the coded values of S and D . The term ' \bar{Y} ' indicates a mean value while ' \hat{Y} ' indicates an estimate of the value.

Experiment 1i Total Plant Weight

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.7154
Duration	2	8.1261
Interaction	4	3.3325
Error	27	3.4046

No response surface fitted.

$$\bar{Y} = 10.72$$

Control. 13.42

L.S.D. 5 %. 2.68

C.V. 17.2 %

ii Shoot Weight

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.8888
Duration	2	1.1393
Interaction	4	1.7362
Error	27	1.1126

No response surface fitted.

$$\bar{Y} = 6.13$$

Control. 8.40

L.S.D. 5 %. 1.53

C.V. 18.6 %

iii Root Weight

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.0072
Duration	D_L 1	1.0732
	D_Q 1	4.6691 * *
Interaction	4	0.3037
(Lack of Fit)	(7)	(0.3289)
Error	27	0.7205

Fitted surface. $\hat{Y} = 18.291 - 1.019 D^2$

Y values. 4.83, 5.01, 3.96, 4.42, 4.91, 4.33, 4.34, 5.33, 4.03.

\hat{Y} values. 4.32, 5.08, 4.32, 4.32, 5.08, 4.32, 4.32, 5.08, 4.32.

Control. 5.02

L.S.D. 5%. 1.23

C.V. 18.6%

iv Root/Shoot Ratio

Source	Degrees of Freedom	Mean Sum of Squares
Stage	S_L 1	0.004014
	S_Q 1	0.023762 t
Duration	D_L 1	0.004591
	D_Q 1	0.033541 *
Interaction	$S_Q \cdot D_Q$ 1	0.036100 *
	remainder 3	0.002833
(Lack of Fit)	(5)	(0.003421)
Error	27	0.006418

Fitted surface. $\hat{Y} = 2.994 + 0.073 S^2 - 0.086 D^2 + 0.063 S^2 \cdot D^2$

Y values. 0.793, 0.769, 0.777, 0.688, 0.819, 0.630, 0.742, 0.787, 0.733

\hat{Y} values. 0.761, 0.778, 0.761, 0.659, 0.818, 0.659, 0.761, 0.778, 0.761

Control. 0.604

L.S.D. 5% 0.116

C.V. 10.7%

Experiment 2.i Cotyledon Number.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S _L	1	2.8336	* *
	S _Q	1	0.6690	* *
Duration	D _L	1	1.2844	* *
	D _Q	1	0.0237	
Interaction		4	0.1258	
(Lack of Fit)		(5)	(0.1054)	
Error		45	0.0798	

Fitted surface. $\hat{Y} = 7.044 - 1.684 S + 0.472 S^2 - 1.13 D$

Y values. 1.6, 1.6, 1.4, 1.3, 1.1, 0.7, 1.3, 0.8, 0.9.

\hat{Y} values. 1.7, 1.5, 1.3, 1.2, 1.0, 0.8, 1.2, 1.0, 0.8.

Control. 1.5

L.S.D. 5%. 0.03

C.V. 24.1%

ii Unifoliate Leaf Number

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S _L	1	0.071111	* *
	S _Q	1	0.053330	* *
Duration	D _L	1	0.033611	*
	D _Q	1	0.000833	
Interaction		4	0.007779	
(Lack of Fit)		(5)	(0.006390)	
Error		45	0.006296	

Fitted surface. $\hat{Y} = 5.533 - 0.267 S - 0.133 S^2 - 0.183 D$

Y values. 0.97, 0.97, 0.90, 0.97, 1.00, 0.93, 0.92, 0.82, 0.83.

\hat{Y} values. 0.98, 0.95, 0.91, 1.00, 0.97, 0.94, 0.89, 0.86, 0.83.

Control. 0.95

L.S.D. 5%. 0.09

C.V. 8.6%

iii Trifoliolate Leaf Number.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.003889
Duration	2	0.028899
Interaction	4	0.092778
Error	45	0.049258

No response surface fitted.

Control. 2.6

L.S.D. 5%. -

C.V. 8.6%

iv Cotyledon Leaf Area

Source	Degrees of Freedom	Mean Sum of Squares
Stage	S_L 1	0.006944 * *
	S_Q 1	0.000333
Duration	D_L 1	0.005878 * *
	D_Q 1	0.000033
Interaction	$S_L \cdot D_L$ 1	0.004201 *
	$S_Q \cdot D_Q$ 1	0.012604 * *
	remainder 2	0.000620
(Lack of Fit)	()	(0.000527)
Error	45	0.000577

Fitted surface. $\hat{Y} = 0.503 - 0.083 S - 0.077 D + 0.046 S \cdot D^2 + 0.046 S \cdot D^2$

Y values. 0.11, 0.10, 0.10, 0.08, 0.11, 0.05, 0.11, 0.04, 0.07.

\hat{Y} values. 0.11, 0.10, 0.08, 0.08, 0.11, 0.06, 0.10, 0.04, 0.07

Control. 0.10

L.S.D. 5%. 0.03

C.V. 28.6%

v Unifoliate Leaf Area

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S _L	1	0.014003	**
	S _G	1	0.016875	**
Duration	D _L	1	0.005136	t
	D _G	1	0.000008	
Interaction				
	S _L .D _L	1	0.006667	t
	S _G .D _G	1	0.018150	**
	remainder	2	0.001492	
(Lack of Fit)		(3)	(0.000997)	
Error		45	0.001755	

Fitted surface. $\hat{Y} = 1.58 - 0.118 S - 0.075 S^2 - 0.072 D - 0.10 S_L \cdot D_L + 0.055 S^2 \cdot D^2$

Y values. 0.27, 0.27, 0.29, 0.28, 0.33, 0.26, 0.27, 0.20, 0.22.

\hat{Y} values. 0.28, 0.25, 0.28, 0.28, 0.33, 0.26, 0.27, 0.21, 0.21.

Control. 0.34

L.S.D. 5%. 0.05

C.V. 15.9%

vi Trifoliate Leaf Area.

Source		Degrees of Freedom	Mean Sum of Squares
Stage		2	0.0698
Duration		2	0.1954
Interaction		4	0.0723
Error		45	0.1213

No response surface fitted.

$\bar{Y} = 1.99$

Control. 2.35

L.S.D. 5% 0.41

C.V. 17.5

vii Total Leaf Area.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.0609
Duration	2	0.2250
Interaction	4	0.0819
Error	45	0.1130

No response surface fitted.

$$\bar{Y} = 2.34$$

Control. 2.79

L.S.D. 5%. 0.42

C.V. 14.1%

viii Cotyledon Weight.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	S_L 1	0.078400 **
	S_Q 1	0.013333 t
Duration	D_L 1	0.045511 **
	D_Q 1	0.000133
Interaction	4	0.003572
(Lack of Fit)	(5)	(0.003705)
Error	45	0.003495

Fitted surface. $\hat{Y} = 1.306 - 0.28 S + 0.067 S^2 - 0.21 D$

Y values. 0.28, 0.30, 0.25, 0.24, 0.20, 0.14, 0.23, 0.16, 0.16.

\hat{Y} values. 0.31, 0.28, 0.24, 0.23, 0.20, 0.16, 0.22, 0.18, 0.15

Control. 0.25

L.S.D. 5%. 0.07

C.V. 27.1

ix Unifoliolate Leaf Weight

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.0182	t
	S_Q	1	0.0839	* *
Duration		2	0.0103	
Interaction				
	$S_{L \cdot D_Q}$	1	0.0180	t
	remainder	3	0.0045	
(Lack of Fit)		(5)	(0.0068)	
Error		45	0.0061	

Fitted surface. $\hat{Y} = 3.139 - 0.135 S - 0.167 S^2 + 0.095 S_{L \cdot D_Q}$
 Y values. 0.49, 0.57, 0.49, 0.60, 0.57, 0.56, 0.52, 0.46, 0.44.
 \hat{Y} values. 0.50, 0.55, 0.50, 0.58, 0.58, 0.58, 0.49, 0.44, 0.49.
 Control. 0.63
 L.S.D. 5%. 0.09
 C.V. 14.9

x Trifoliolate Leaf Weight

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.6615	
	S_Q	1	2.6258	*
Duration		2	0.4129	
Interaction		4	0.2406	
(Lack of Fit)		(7)	(0.3500)	
Error		45	0.3742	

Fitted surface. $\hat{Y} = 23.17 - 0.936 S^2$
 Y values. 3.48, 3.73, 3.50, 3.95, 4.02, 4.54, 3.67, 3.91, 3.95.
 \hat{Y} values. 3.71, 3.71, 3.71, 4.17, 4.17, 4.17, 3.71, 3.71, 3.71.
 Control. 5.22
 L.S.D. 5% 0.71
 C.V. 15.8%

xi Total Leaf Weight

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.3117	
	S_Q	1	3.3100	* *
Duration		2	0.1617	
Interaction		4	0.3334	
(Lack of Fit)		(7)	(0.2812)	
Error		45	0.4191	

Fitted surface. $\hat{Y} = 27.59 - 1.05 S^2$

Y values. 4.26, 4.60, 4.13, 4.80, 4.80, 5.25, 4.41, 4.53, 4.62.

\hat{Y} values. 4.42, 4.42, 4.42, 4.95, 4.95, 4.95, 4.42, 4.42, 4.42.

Control. 6.08

L.S.D. 5%. 0.75

C.V. 14.1

xii Stem Weight

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	1.2321	*
	S_Q	1	0.2621	
Duration		2	0.1358	
Interaction		4	0.2504	
(Lack of Fit)		(7)	(0.2199)	
Error		45	0.2413	

Fitted surface. $\hat{Y} = 17.97 + 0.11 S$

Y values. 2.82, 2.74, 2.68, 3.00, 2.85, 3.39, 2.93, 3.24, 3.16.

\hat{Y} values. 2.79, 2.79, 2.79, 2.98, 2.98, 2.98, 3.16, 3.16, 3.16.

Control. 4.33

L.S.D. 5%. 0.57

C.V. 16.6%

xiii Root Weight

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.0043
Duration	2	0.4512
Interaction	4	0.0921
Error	45	0.4998

No response surface fitted.

$$\bar{Y} = 3.96$$

Control. 4.81

L.S.D. 5%. 0.82

C.V. 17.8%

xiv Shoot Weight

Source	Degrees of Freedom	Mean Sum of Squares
Stage	1	2.8230
	1	5.4002 *
Duration	2	0.4938
Interaction	4	1.0043
(Lack of Fit)	(7)	(0.9779)
Error	45	1.2077

Fitted surface. $\hat{Y} = 45.47 - 1.342 s^2$

Y values. 7.08, 7.34, 6.81, 7.80, 7.61, 8.64, 7.36, 7.78, 7.77.

\hat{Y} values. 7.35, 7.35, 7.35, 8.03, 8.03, 8.03, 7.35, 7.35, 7.35.

Control. 10.41

L.S.D. 5%. 1.28

C.V. 14.5%

xv Total Plant Weight

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	3.9933
Duration	2	0.2905
Interaction	4	1.1882
Error	45	2.8124

No response surface fitted.

$\bar{Y} = 11.54$

Control. 15.21

L.S.D. 5%. 1.95

C.V. 14.5%

xvi Root/Shoot Ratio

Source	Degrees of Freedom	Mean Sum of Squares
Stage S_L	1	0.014360 t
S_Q	1	0.027616 *
Duration D_L	1	0.020928 *
D_Q	1	0.013646 t
Interaction	4	0.004778
(Lack of Fit)	(4)	(0.004778)
Error	45	0.004395

Fitted surface. $\hat{Y} = 3.15 - 0.12 S + 0.096 S^2 - 0.144 D + 0.067 D^2$

Y values. 0.573, 0.531, 0.583, 0.550, 0.480, 0.453, 0.562, 0.501, 0.505.

\hat{Y} values. 0.596, 0.539, 0.548, 0.528, 0.471, 0.480, 0.556, 0.498, 0.508.

Control. 0.466

L.S.D. 5%. 0.077.

C.V. 12.6%

xvii Root/Leaf Ratio

Source		Degrees of Freedom	Mean Sum of Squares
Stage	S_L	1	0.012395
	S_Q	1	0.113945 * *
Duration	D_L	1	0.052823 *
	D_Q	1	0.048939 *
Interaction		4	0.012345
(Lack of Fit)		(5)	(0.012355)
Error		45	0.011341

Fitted surface. $\hat{Y} = 5.203 + 0.195 S^2 - 0.23 D + 0.128 D^2$

Y values. 0.949, 0.847, 0.958, 0.893, 0.770, 0.745, 0.933, 0.857, 0.848.

\hat{Y} values. 0.959, 0.857, 0.882, 0.862, 0.760, 0.785, 0.959, 0.857, 0.882.

Control. 0.800

L.S.D. 5% 0.124

C.V. 12.3%

xviii Root/Stem Ratio

Source		Degrees of Freedom	Mean Sum of Squares
Stage	S_L	1	0.270747 *
	S_Q	1	0.077227
Duration	D_L	1	0.141251 t
	D_Q	1	0.048091
Interaction			
	$D_L.S_Q$	1	0.114561 t
	remainder	3	0.030555
(Lack of Fit)		(5)	(0.043397)
Error		45	0.033980

Fitted surface. $\hat{Y} = 8.091 - 0.52 D - 0.376 D + 0.239 D.S^2$

Y values. 1.447, 1.430, 1.503, 1.444, 1.282, 1.159, 1.406, 1.207, 1.252.

\hat{Y} values. 1.458, 1.435, 1.412, 1.490, 1.349, 1.206, 1.285, 1.262, 1.239.

Control. 1.120

L.S.D. 5% 0.230

C.V. 14.6%

xix Stem/Leaf Ratio

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.025653	* *
	S_Q	1	0.018382	*
Duration		2	0.002398	
Interaction				
	$S_L \cdot D_Q$	1	0.013209	*
	remainder	3	0.001457	
(Lack of Fit)		(5)	(0.001833)	
Error		45	0.003117	

Fitted surface. $\hat{Y} = 3.889 + 0.16 S + 0.73 S^2 - 0.095 S \cdot D^2$

Y values. 0.660, 0.597, 0.647, 0.625, 0.596, 0.645, 0.667, 0.714, 0.682.

\hat{Y} values. 0.650, 0.603, 0.650, 0.622, 0.622, 0.622, 0.672, 0.720, 0.672.

Control. 0.713

L.S.D. 5%. 0.065

C.V. 8.6%

Experiment 3i Total Plant Weight

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.6224	
	S_Q	1	30.4915	* *
Duration		2	0.4616	
Interaction				
	$S_L \cdot D_Q$	1	24.7397	* *
	$S_Q \cdot D_Q$	1	16.6022	* *
	remainder	2	2.0981	
(Lack of Fit)		(5)	(1.1480)	
Error		27	1.6884	

Fitted surface. $\hat{Y} = 37.64 + 2.603 S^2 - 2.875 S \cdot D^2 + 1.358 S^2 \cdot D^2$

Y values. 12.09, 7.89, 10.70, 7.32, 9.25, 7.76, 9.32, 10.44, 9.94.

\hat{Y} values. 11.12, 7.94, 11.12, 7.43, 9.47, 7.43, 9.68, 10.82, 9.68.

Control. 10.21

L.S.D. 5% 1.89

C.V. 14.4%

ii Shoot Weight

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.0651	
	S_Q	1	3.8781	*
Duration		2	0.1265	
Interaction				
	$S_L \cdot D_Q$	1	9.4164	**
	$S_Q \cdot D_Q$	1	2.9156	*
	remainder	2	0.6293	
(Lack of Fit)		(5)	(0.3155)	
Error		27	0.6940	

Fitted surface. $\hat{Y} = 21.933 + 0.928 S^2 - 1.172 S \cdot D^2 + 0.569 S^2 \cdot D^2$

Y values. 6.56, 4.67, 6.07, 4.46, 5.67, 4.93, 5.08, 6.34, 5.57.

\hat{Y} values. 6.30, 4.54, 6.30, 4.73, 5.59, 4.73, 5.41, 6.32, 5.41.

Control. 6.48

L.S.D. 5% 1.21

C.V. 16.4%

iii Root Weight

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.284926	
	S_Q	1	12.454209	**
Duration	D_L	1	0.418704	
	D_Q	1	1.502222	*
Interaction				
	$S_L \cdot D_L$	1	1.058327	t
	$S_L \cdot D_Q$	1	3.649276	**
	$S_Q \cdot D_Q$	1	5.762000	**
	remainder	1	0.173397	
(Lack of Fit)		(3)	(0.292342)	
Error		27	0.313145	

Fitted surface. $\hat{Y} = 15.72 + 1.664 S^2 + 0.578 D^2 + 1.029 S \cdot D - 1.103 S \cdot D^2 + 0.8 S^2 \cdot D^2$

Y values. 5.53, 3.22, 4.63, 2.86, 3.61, 2.83, 4.24, 4.10, 4.37.

\hat{Y} values. 5.22, 3.11, 4.71, 2.84, 3.61, 2.84, 4.16, 4.21, 4.67.

Control. 3.73

L.S.D. 5% 0.82

C.V. 14.6%

iv Root/Shoot Ratio

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.000662	
	S_Q	1	0.175035	* *
Duration	D_L^2	1	0.026467	*
	D_Q	1	0.043412	*
Interaction				
	$S_Q \cdot D_Q$	1	0.046908	*
	remainder	3	0.001731	
(Lack of Fit)		(4)	(0.001501)	
Error		27	0.006177	

Fitted surface. $\hat{Y} = 2.805 + 0.197 S^2 - 0.133 D + 0.104 D^2 + 0.072 S^2 \cdot D^2$
 Y values. 0.345, 0.703, 0.766, 0.642, 0.639, 0.571, 0.840, 0.653, 0.738
 \hat{Y} values. 0.843, 0.679, 0.776, 0.641, 0.633, 0.575, 0.843, 0.679, 0.776.

Control. 0.576

L.S.D. 5%. 0;114

C.V. 11.2%

Appendix IIProgress Curve Analyses For Control Plants.Experiment 1i. Total Plant Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	2.270752 * *
Deviations	9	0.017710

Fitted equation. $\log W = \log 0.0637 X - \log 0.6725$

R.G.R. = 0.147 mg/mg/day

ii Shoot Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	1.892027 * *
Deviations	9	0.012695

Fitted equation. $\log W = \log 0.0581 X - \log 0.7944$

R.G.R. = 0.134 mg/mg/day

iii Root Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	3.050966 * *
Deviations	9	0.038187

Fitted equation. $\log W = \log 0.0738 X - \log 1.2687$

R.G.R. = 0.170 mg/mg/day

Experiment 2i Total Plant Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	2.233919 * *
Deviations	9	0.002697

Fitted equation. $\log W = \log 0.0632 X - \log 0.6621$

R.G.R. = 0.145 mg/mg/day

ii Shoot Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	1.865499 * *
Deviations	9	0.004989

Fitted equation. $\log W = \log 0.0577 X - \log 0.7364$

R.G.R. = 0.133 mg/mg/day

iii Root Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	2.609824 * *
Deviations	9	0.005645

Fitted equation. $\log W = \log 0.0693 X - \log 1.3450$

R.G.R. = 0.160 mg/mg/day

iv Total Leaf Area

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	2.179323 * *
Deviations	9	0.007762

Fitted equation. $\log A = \log 0.0626 X - \log 1.3399$

R.L.A.G.R. = 0.144 cm²/cm²/day

Experiment 3i Total Plant Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	1.607370 * *
Deviations	9	0.004554

Fitted equation. $\log W = \log 0.0536 X - \log 0.4943$

R.G.R. = 0.123 mg/mg/day

ii Shoot Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	1.312860 * *
Deviations	9	0.006178

Fitted equation. $\log W = \log 0.0434 X - \log 0.5935$

R.G.R. = 0.112 mg/mg/day

iii Root Weight

Source	Degrees of Freedom	Mean Sum of Squares
Mean	1	
Regression	1	2.265445 * *
Deviations	9	0.006790

Fitted equation. $\log W = \log 0.0636 X - \log 1.1352$

R.G.R. = 0.146 mg/mg/day

Appendix IIIAnalyses of Variance For Growth Analysis Data.

In the tables to follow, the letters ' S ' and ' D ' refer to stage of growth and duration of wind respectively while the sub - scripts ' L ' and ' Q ' refer to the linear and quadratic components of the source of variance. The lack of fit term bracketed in the individual tables is comprised of all the terms in the analysis that are not significant at the P = 0.01 level. The fitted surface equation coefficients are applicable only in conjunction with the coded values of S and D. The term ' \bar{Y} ' indicates a mean value while ' \hat{Y} ' indicates an estimate of the value.

Experiment 1.i R.G.R. of total plant during wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S _L	1	0.065208	**
	S _Q	1	0.035245	**
Duration		2	0.000736	
Interaction		4	0.009914	
(Lack of fit)		(6)	(0.006732)	
Error		27	0.006721	

Fitted surface. $\hat{Y} = 0.567 - 0.209 S - 0.089 S^2$

Y values. 0.183, 0.165, 0.167, 0.231, 0.148, 0.179, 0.002, 0.096, 0.105.

\hat{Y} values. 0.172, 0.172, 0.172, 0.186, 0.186, 0.186, 0.068, 0.068, 0.068.

Control, 0.146

L.S.D. 5 %. 0.119

C.V. 57.9 %

ii R.G.R. of total plant after wind.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.003575
Duration	2	0.002512
Interaction	4	0.001654
Error	27	0.001613

No response surface fitted.

$$\bar{Y} = 0.131$$

Control. 0.146

L.S.D. 5 %. 0.058

C.V. 30.6 %

iii R.G.R. shoot during wind.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	S_L 1	0.126876 **
	S_Q 1	0.019306 *
Duration	D_L 1	0.021540 *
	D_Q 1	0.006216
Interaction	$S_L \cdot D_L$ 1	0.043786 **
	$S_L \cdot D_Q$ 1	0.010414 t
	$D_L \cdot S_Q$ 1	0.010651 t
	remainder 1	0.000077
(Lack of fit)	(2)	(0.006393)
Error	27	0.003035

$$\text{Fitted surface. } \hat{Y} = 0.608 - 0.291 S - 0.066 S^2 - 0.12 D + 0.218 S \cdot D - 0.059 S \cdot D^2 + 0.060 D \cdot S^2$$

Y values. 0.299, 0.162, 0.164, 0.255, 0.163, 0.136, 0.020, 0.075, 0.095

\hat{Y} values. 0.322, 0.179, 0.153, 0.244, 0.222, 0.125, 0.009, 0.094, 0.088

Control, 0.134

L.S.D. 5 %. 0.080

C.V. 36.2 %

iv R.G.R. shoot after wind.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.005922
Duration	2	0.000835
Interaction	4	0.000918
Error	27	0.003603

No response surface fitted.

$$\bar{Y} = 0.129$$

Control. 0.134

L.S.D. 5 %. 0.087

C.V. 46.7 %

v R.G.R.root during wind.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	S_L 1	0.075488 * *
	S_Q 1	0.183416 * *
Duration	2	0.005963
Interaction		
	$S_Q \cdot D_L$ 1	0.136854 * *
	$S_Q \cdot D_Q$ 1	0.035753 *
	remainder 2	0.014229
(Lack of fit)	(4)	(0.010097)
Error	27	0.008192

$$\text{Fitted surface. } \hat{Y} = 0.748 - 0.224 S - 0.202 S^2 + 0.214 D \cdot S^2 - 0.063 S^2 \cdot D^2$$

Y values. 0.196, 0.173, 0.210, 0.452, 0.207, 0.206, - 0.011, 0.128, 0.125.

\hat{Y} values. 0.124, 0.224, 0.231, 0.427, 0.225, 0.213, 0.012, 0.112, 0.119.

Control. 0.170

L.S.D. 5 %. 0.131

C.V. 48.3 %

vi R.G.R. root after wind.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.003337
Duration	2	0.005250
Interaction	4	0.002573
Error	27	0.003493

No response surface fitted.

$$\bar{Y} = 0.126$$

Control. 0.170

L.S.D. 5 % 0.086

C.V. 46.9 %

Experiment 2.i R.G.R. total plant during wind.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	S_L 1	0.015960 * *
	S_Q 1	0.022707 * *
Duration	2	0.002021
Interaction	4	0.001194
(Lack of fit)	(6)	(0.001469)
Error	45	0.001919

Fitted surface. $\hat{Y} = 0.871 - 0.126 S - 0.087 S^2$

Y values. 0.164, 0.153, 0.138, 0.165, 0.196, 0.162, 0.094, 0.123, 0.113.

\hat{Y} values. 0.152, 0.152, 0.152, 0.174, 0.174, 0.174, 0.110, 0.110, 0.110.

Control. 0.145

L.S.D. 5 %. 0.051

C.V. 31.7 %

ii R.G.R. total plant after wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.004692	t
	S_Q	1	0.005306	*
Duration		2	0.002552	
Interaction		4	0.001572	
(Lack of fit)		(6)	(0.001899)	
Error		45	0.001273	

Fitted surface. $\hat{Y} = 0.862 + 0.069 S + 0.042 S^2$

Y values. 0.137, 0.136, 0.140, 0.138, 0.115, 0.132, 0.145, 0.144, 0.193.

\hat{Y} values. 0.139, 0.139, 0.139, 0.130, 0.130, 0.130, 0.162, 0.162, 0.162.

Control. 0.145

L.S.D. 5%. 0.041

C.V. 25.1%

iii R.G.R. shoot during wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.001667	
	S_Q	1	0.016354	**
Duration	D_L	1	0.000003	
	D_Q	1	0.006440	t
Interaction		4	0.004350	
(Lack of fit)		(6)	(0.000568)	
Error		45	0.001876	

Fitted surface. $\hat{Y} = 0.886 - 0.074 S^2 - 0.046 D^2$

Y values. 0.140, 0.152, 0.135, 0.167, 0.195, 0.156, 0.114, 0.143, 0.128.

\hat{Y} values. 0.143, 0.151, 0.143, 0.165, 0.186, 0.165, 0.143, 0.151, 0.143.

Control. 0.133

L.S.D. 5%. 0.050

C.V. 29.3%

iv R.G.R. shoot after wind.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	2	0.001240
Duration	2	0.001469
Interaction	4	0.000258
Error	45	0.001368

No response surface fitted.

$$\bar{Y} = 0.128$$

Control, 0.133

L.S.D. 5 %. 0.043

C.V. 28.8 %

v. R.G.R. root during wind.

Source	Degrees of Freedom	Mean Sum of Squares
Stage	S_L 1	0.004096
	S_Q 1	0.061729 * *
Duration	D_L 1	0.011592 t
	D_Q 1	0.000166
Interaction	4	0.000535
(Lack of Fit)	(6)	(0.001067)
Error	45	0.003652

Fitted surface. $Y = 1.028 - 0.143 S^2 - 0.107 D$

Y values. 0.175, 0.157, 0.143, 0.227, 0.232, 0.199, 0.163, 0.134, 0.114.

Y values. 0.165, 0.148, 0.130, 0.237, 0.219, 0.201, 0.165, 0.148, 0.130.

Control. 0.160

L.S.D. 5 %. 0.070

C.V. 35.3 %

vi R.G.R. root after wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.021805	* *
	S_Q	1	0.030267	* *
Duration	D_L	1	0.009801	*
	D_Q	1	0.005490	t
Interaction				
	$S_L \cdot D_L$	1	0.019437	* *
	$D_L \cdot S_Q$	1	0.016836	* *
	remainder	2	0.001952	
(Lack of fit)		(2)	(0.001952)	
Error		45	0.001684	

Fitted surface. $\hat{Y} = 1.012 + 0.148 S + 0.10 S^2 + 0.099 D + 0.043 D^2 + 0.171 S \cdot D + 0.092 D \cdot S^2$

Y values. 0.158, 0.159, 0.165, 0.155, 0.125, 0.128, 0.165, 0.180, 0.286.

\hat{Y} values. 0.165, 0.146, 0.171, 0.157, 0.121, 0.128, 0.157, 0.196, 0.278.

Control. 0.160

L.S.D. 5 % 0.048

C.V. 24.3 %

vii L.A.R. during wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage		2	0.000542	* *
Duration		2	0.000079	
Interaction		4	0.005116	* *
Error		45	0.000078	

C.V. 0.4 %

viii L.A.R. after wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage		2	0.000958	* *
Duration		2	0.000581	* *
Interaction		4	0.002493	* *
Error		45	0.000070	

C.V. 0.14 %

ix N.A.R. during wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.551554	* *
	S_Q	1	0.721280	* *
Duration		2	0.044679	
Interaction				
	$S_L \cdot D_L$	1	0.151845	t
	$S_Q \cdot D_L$	1	0.214622	*
	remainder	2	0.020983	
(Lack of Fit)		(4)	(0.032831)	
Error		45	0.048028	

Fitted surface. $\hat{Y} = 4.386 - 0.743 S - 0.49 S^2 + 0.477 S \cdot D - 0.328 S^2 \cdot D$

Y values. 0.852, 0.863, 0.604, 0.774, 0.895, 1.014, 0.451, 0.603, 0.522

\hat{Y} values. 0.798, 0.773, 0.639, 0.869, 0.978, 1.088, 0.501, 0.526, 0.550.

Control. 0.690

L.S.D. 5%. 0.254

C.V. 30.0%

x N.A.R. after wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.75282	*
	S_Q	1	0.059080	
Duration	D_L	1	0.132739	t
	D_Q	1	0.048641	
Interaction				
	$S_L \cdot D_L$	1	0.184626	*
	remainder	3	0.058705	
(Lack of fit)		(5)	(0.056767)	
Error		45	0.033054	

Fitted surface. $\hat{Y} = 4.281 + 0.419 S + 0.364 D + 0.526 S \cdot D$

Y values. 0.649, 0.734, 0.619, 0.687, 0.553, 0.761, 0.686, 0.726, 0.994.

\hat{Y} values. 0.671, 0.643, 0.617, 0.653, 0.714, 0.774, 0.635, 0.783, 0.932.

Control. 0.690

L.S.D. 5%. 0.211

C.V. 25.5%

Experiment 3i R.G.R. total plant during wind.

Source		Degrees of Freedom	Mean Sum of Squares
Stage	S_L	1	0.000017
	S_Q	1	0.039574 * *
Duration		2	0.001954
Interaction			
	$D_L \cdot S_Q$	1	0.018644 *
	remainder	3	0.000178
(Lack of fit)		(6)	(0.000743)
Error		27	0.003635

Fitted surface. $\hat{Y} = 0.380 - 0.094 S^2 + 0.079 D \cdot S^2$

Y values. 0.058, 0.063, 0.091, 0.197, 0.124, 0.108, 0.069, 0.061, 0.088.

\hat{Y} values. 0.034, 0.054, 0.091, 0.163, 0.124, 0.103, 0.034, 0.054, 0.091.

Control. 0.123

L.S.D. 5%. 0.087

C.V. 63.5%

ii R.G.R. total plant after wind.

Source		Degrees of Freedom	Mean Sum of Squares
Stage	S_L	1	0.014065 * *
	S_Q	1	0.023148 * *
Duration	D_L	1	0.007957 *
	D_Q	1	0.000416
Interaction			
	$S_L \cdot D_L$	1	0.008327 *
	remainder	3	0.001131
(Lack of fit)		(4)	(0.000952)
Error		27	0.001105

Fitted surface. $\hat{Y} = 0.551 + 0.097 S + 0.072 S^2 + 0.073 D + 0.091 S \cdot D$

Y values. 0.137, 0.120, 0.137, 0.087, 0.115, 0.104, 0.128, 0.193, 0.219.

\hat{Y} values. 0.136, 0.132, 0.127, 0.084, 0.102, 0.120, 0.139, 0.180, 0.221.

Control, 0.123

L.S.D. 5%. 0.048

C.V. 24.1%

iii R.G.R. shoot during wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.009720	t
	S_Q	1	0.046971	* *
Duration		2	0.003343	
Interaction				
	$D_L \cdot S_Q$	1	0.022102	* *
	remainder	3	0.002041	
(Lack of fit)		(5)	(0.002562)	
Error		27	0.002765	

Fitted surface. $\hat{Y} = 0.379 - 0.081 S - 0.102 S^2 + 0.086 D \cdot S^2$

Y values. 0.089, 0.094, 0.086, 0.220, 0.113, 0.105, 0.034, 0.051, 0.063.

\hat{Y} values. 0.045, 0.090, 0.111, 0.189, 0.146, 0.105, 0.028, 0.049, 0.071.

Control. 0.112

L.S.D. 5% 0.092

C.V. 66.5%

iv R.G.R. shoot after wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.026268	* *
	S_Q	1	0.025538	* *
Duration	D_L	1	0.014211	* *
	D_Q	1	0.000288	
Interaction				
	$S_L \cdot D_L$	1	0.015314	* *
	remainder	3	0.001550	
(Lack of fit)		(4)	(0.001234)	
Error		27	0.001365	

Fitted surface. $\hat{Y} = 0.520 + 0.132 S + 0.075 S^2 + 0.097 D + 0.124 S \cdot D$

Y values. 0.122, 0.103, 0.122, 0.074, 0.106, 0.097, 0.114, 0.194, 0.238

\hat{Y} values. 0.123, 0.116, 0.109, 0.068, 0.093, 0.117, 0.127, 0.182, 0.237.

Control. 0.112

L.S.D. 5%. 0.054

C.V. 24.4%

v R.G.R. root during wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.020300	*
	S_Q	1	0.018753	t
Duration		2	0.003716	
Interaction		4	0.004496	
(Lack of fit)		(6)	(0.004236)	
Error		27	0.005033	

Fitted surface. $Y = 0.407 + 0.116 S - 0.065 S^2$

Y values. 0.041, 0.025, 0.104, 0.158, 0.136, 0.108, 0.146, 0.083, 0.126.

Y values. 0.057, 0.057, 0.057, 0.134, 0.134, 0.134, 0.115, 0.115, 0.115.

Control. 0.146

L.S.D. 5%. 0.103

C.V. 69.7%

vi R.G.R. root after wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Stage	S_L	1	0.001320	
	S_Q	1	0.019339	*
Duration		2	0.001653	
Interaction		4	0.001433	
(Lack of fit)		(7)	(0.001480)	
Error		27	0.002107	

Fitted surface. $Y = 0.593 + 0.066 S^2$

Y values. 0.168, 0.157, 0.163, 0.111, 0.132, 0.120, 0.142, 0.191, 0.200.

Y values. 0.165, 0.165, 0.165, 0.115, 0.115, 0.115, 0.165, 0.156, 0.165.

Control. 0.146

L.S.D. 5%. 0.067

C.V. 22.7%

Combined Relative Growth Rate Data.i R.G.R. total plant during wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Wind	W_L	1	0.015225	t
	W_Q	1	0.009217	
Stage	S_L	1	0.042195	* *
	S_Q	1	0.098859	* *
Duration		2	0.000366	
Interaction				
W x S	$W_L.S_L$	1	0.033974	* *
	remainder	3	0.002325	
W x D		4	0.002106	
S x D		4	0.009247	
W x S x D		8	0.003874	
(Lack of fit)		(22)	(0.004242)	
Error		81	0.004295	

Fitted surface. $\hat{Y} = 0.534 - 0.058 W - 0.097 S - 0.086 S^2 + 0.106 W.S$
 C.V. 49.0 %

ii R.G.R. total plant after wind.

Source		Degrees of Freedom	Mean Sum of Squares	
Wind		2	0.009688	* *
Stage		2	0.026620	* *
Duration		2	0.002647	
Interaction				
W x S		4	0.003520	*
W x D		4	0.004001	*
S x D		4	0.002058	
W x S x D		8	0.002522	
Error		81	0.001281	

No response surface fitted.

C.V. 24.6 %

iii R.G.R. shoot during wind.

Source	Degrees of Freedom	Mean Sum of Squares	
Wind	2	0.026545	* *
Stage	2	0.083184	* *
Duration	2	0.009449	*
Interaction			
W x S	4	0.015467	* *
W x D	4	0.005338	
S x D	4	0.014423	* *
W x S x D	8	0.005316	
Error	81	0.002900	

No response surface fitted.

C.V. 39.7 %

iv R.G.R. shoot after wind.

Source	Degrees of Freedom	Mean Sum of Squares	
Wind	2	0.007904	*
Stage	2	0.029783	* *
Duration	2	0.005924	t
Interaction			
W x S	4	0.006982	*
W x D	4	0.003311	
S x D	4	0.003439	
W x S x D	8	0.002593	
Error	81	0.002052	

No response surface fitted.

C.V. 32.9 %

v R.G.R. root during wind.

Source	Degrees of Freedom	Mean Sum of Squares	
Wind	2	0.050447	* *
Stage	2	0.107988	* *
Duration	2	0.007621	
Interaction			
W x S	4	0.034305	* *
W x D	4	0.003009	
S x D	4	0.020425	*
W x S x D	8	0.018042	*
Error	81	0.005492	

No response surface fitted.

C.V. 47.2 %

vi R.G.R. root after wind.

Source	Degrees of Freedom	Mean Sum of Squares	
Wind	2	0.023979	* *
Stage	2	0.021880	* *
Duration	2	0.000247	
Interaction			
W x S	4	0.004634	t
W x D	4	0.005655	*
S x D	4	0.001676	
W x S x D	8	0.004365	t
Error	81	0.002241	

No response surface fitted.

C.V. 30.4 %

Appendix IV.Relative Water Content (R.W.C.)...Experiment 2.i R.W.C. Stage of growth 'A' and duration 'D'.

Mean of control	83.73 %
Mean of treatment	<u>84.04 %</u>

$$t = 2.076 \text{ n.s.}$$

ii R.W.C. stage of growth 'A' and durations 'D + 2' & 'E'

Source	Degrees of Freedom	Mean Sum of Squares	
Plant leaf	1	1030.0390	* *
Wind treatment	2	182.8729	* *
Interaction	2	94.5945	* *
Error	30	8.5039	

C.V. 3.3 %

iii R.W.C. Stage of growth 'A' and durations 'E + 2' & 'F'

Source	Degrees of Freedom	Mean Sum of Squares	
Plant leaf	1	421.3440	* *
Wind treatment	2	31.8186	*
Interaction	2	7.0985	
Error	30	6.5194	

C.V. 3.0 %

iv R.W.C. Stage of growth 'A' and wind duration 'F + 2'

Source	Degrees of Freedom	Mean Sum of Squares	
Plant leaf	1	178.7941	* *
Wind treatment	1	9.0100	
Interaction	1	0.4704	
Error	28	5.1682	

C.V. 2.2 %

v R.W.C. Stage of growth 'B' and duration 'D'

Source	Degrees of Freedom	Mean Sum of Squares	
Plant leaf	2	260.4684	* *
Wind treatment	1	342.4957	* *
Interaction	2	11.8381	
Error	30	17.9094	

C.V. 4.2%

vi R.W.C. Stage of growth 'B' and durations 'D + 2' & 'E'

Source	Degrees of Freedom	Mean Sum of Squares	
Plant leaf	2	672.3818	* *
Wind treatment	2	83.7303	* *
Interaction	4	23.4369	*
Error	27	7.6070	

C.V. 2.9%

vii R.W.C. Stage of growth 'B' and durations 'E + 2' & 'F'

Source	Degrees of Freedom	Mean Sum of Squares	
Plant leaf	2	562.8900	* *
Wind treatment	2	47.0092	* *
Interaction	4	13.4333	*
Error	45	4.1337	

C.V. 1.8%

viii R.W.C. Stage of growth 'B' and duration 'F + 2'

Source	Degrees of Freedom	Mean Sum of Squares	
Plant leaf	2	121.5897	* *
Wind treatment	1	29.1600	* *
Interaction	2	0.3737	
Error	30	3.0502	

C.V. 1.9%

ix R.W.C. Stage of growth 'C' and duration 'D'

Source	Degrees of Freedom	Mean Sum of Squares
Plant leaf	2	291.1775 * *
Wind treatment	1	10.1442
Interaction	2	0.1099
Error	30	6.7248

C.V. 2.6 %

x R.W.C. Stage of growth 'C' and durations 'D + 2' & 'E'

Source	Degrees of Freedom	Mean Sum of Squares
Plant leaf	2	232.0144 * *
Wind treatment	2	151.1300 * *
Interaction	4	0.6519
Error	45	2.7317

C.V. 1.6 %

xi R.W.C. Stage of growth 'C' and durations 'E + 2' & 'F'

Source	Degrees of Freedom	Mean Sum of Squares
Plant leaf	2	322.9603 * *
Wind treatment	2	236.4448 * *
Interaction	4	3.4819
Error	36	3.7093

C.V. 2.1 %

xii R.W.C. Stage of growth 'C' and duration 'F + 2'

Source	Degrees of Freedom	Mean Sum of Squares
Plant leaf	2	79.4516 * *
Wind treatment	1	1.8952
Interaction	2	2.4397
Error	29	2.0393

C.V. 1.5 %