Modification of micrometeorological parameters by full-awned, half-awned, and nonawned isogenic barley

by John Frank Benci

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
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Abstract:
The modification of micfometeorological parameters by full-awned, half-awned and nonawned isogenic lines of barley was studied, Aero-dynamics of full-awned and nonawned Atlas barley indicated that awns increased the roughness parameter and elastic properties of a barley canopy. As a result, the sensible heat flux to the atmosphere was considerably higher op the full-awned plot.

After awn emergence, net radiation was 100 ly/day higher over the full-awned as compared to the other isogenic lines. Latent and air-sensible heat accounted for 20 and 80% of the increased net radiation, respectively. The increased dissipation of solar energy by the awned plants resulted in higher air and lower canopy temperatures on full-awned as compared to nonawned barley plots.

Net photosynthesis was 3.4 mg CO_2/hr/ear for full-awned ears as compared to 0.46 mg CO_2/hr/ear for nonawned ears.

No significant differences ($P = .05$) in grain yield, water use efficiency, and total evapotranspiration were found between the isogenic lines of barley. Kernel plumpness and test weight were higher for the awned lines, whereas percent crude protein varied among the isogenic cultivars tested.

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Date May 26, 1971

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Chairman, Examining Committee

Graduate Dean

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ABSTRACT

The modification of micrometeorological parameters by full-awned, half-awned, and nonawned isogenic lines of barley was studied. Aerodynamics of full-awned and nonawned Atlas barley indicated that awns increased the roughness parameter and elastic properties of a barley canopy. As a result, the sensible heat flux to the atmosphere was considerably higher on the full-awned plot.

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INTRODUCTION

Knowledge obtained through research and development of new isogenic cultivars with different morphological characteristics is improving the prospect of attaining the ideal plant for a given climate. Possibilities exist for crop varietal selection for improved water use efficiency, evaporation and transpiration control, and energy consumption in photosynthesis. A convenient means of evaluating the responses of morphologically different plants is to examine the absorption and disposition of energy by them (10).

My over-all objectives were to investigate the influence of barley ears on the turbulent characteristics of the lower atmospheric boundary and on the partitioning of net radiation. Altering the energy absorption and disposition properties of a canopy should have a bearing on evapotranspiration and the heating of the plants and adjacent air layers. Previous work done by personnel at the Plant and Soils Department of Montana State University indicated that awns influence albedo, head temperatures, and transpiration. Isolation of various awn lengths was accomplished through use of isogenic lines of barley made available by Mr. Robert Eslick.

The specific objectives of this study were:

1. To determine the partitioning of net radiation by full-awned, half-awned, and nonawned isogenic lines of barley.
2. To compare aerodynamic characteristics of full-awned and

nonawned Atlas barley.

3. To compare net CO_2 assimilation of full-awned and nonawned isogenic Atlas and Betzes barley ears in the laboratory.
4. To compare kernel plumpness, protein, test weight, and yield of awned and nonawned isogenes.

LITERATURE REVIEW

Awn Characteristic in Influencing Grain Yield, Kernel Weight, and Water Use

The effect of awns on productivity and quality of cereals has challenged agronomists for many decades (43). Various techniques have been employed to demonstrate the role of the awn. Examples include shading, clipping, $C^{14}O_2$ uptake, and comparison of isogenic lines differing in awn length. Isogenic lines provide the best material for study (50).

Grain development after ovule fertilization in wheat and barley may be seriously impeded if "optimum" conditions do not prevail in the photosynthetically active plant parts (52). The most critical part of the cereal plant affecting production of grain appears to be the spike (6, 61, 49). Saghir, Khan, and Worzella (52) found that clipping awns at anthesis reduced grain yield by 20.8% and grain weight by 13.4%. They also demonstrated that shading the spike affected grain yield and kernel weight more critically than did shading other organs of the plant. Awned lines of wheat have been shown to produce higher yields, heavier kernels, and higher test weights than nonawned lines (37, 3). On the other hand, there have been cases where no significant difference in grain yield between awned and nonawned lines were found (29, 21).

Awns also function in transpiration as found by Pool and Patterson (48) and McDonough and Gauch (36). They concluded that awns on wheat spikes have a twofold function: (a) increasing moisture uptake in the absorption phase (after a rain or dew) and (b) increasing moisture loss in the drying phase.

Photosynthesis

Most of the dry matter in the grain of barley is produced from carbohydrate assimilated by leaves, stems, and ears after ear emergence (1, 49, 61, 62). Porter, Pal, and Martin (49) suggested that 25% of the final ear weight is present at ear emergence, 30% is contributed by ear photosynthesis, and the remaining 45% is supplied by the other organs of the plant. Thorne (61) found that photosynthesis in barley ears accounted for 40% of the carbohydrate in the grain. Experiments with ears of barley and wheat exposed to radioactive carbon have illustrated a movement of the radioactive carbon towards the grain and little towards the shoots (6, 34, 36). Carr and Wardlaw (7) showed that 49% of the carbon assimilated by the flag leaf blade and up to 80% assimilated by the glumes moved to the grain. Shading experiments by Watson, Thorne, and French (69) indicated that shoots contribute about 15% to grain dry weight.

Porter, et al. (49) demonstrated that the CO_2 assimilation rate by barley ears remained practically constant at 1.45 mg/hr for about 18 days after ear emergence and then fell to zero toward maturity. Carr and Wardlaw (7) showed that photosynthesis by the ears of wheat continued to increase for 15 days after anthesis while photosynthesis by leaves declined after anthesis. They also showed that photosynthesis by wheat ears was equivalent to that of the upper two leaf blades for two nonawned cultivars and considerably higher than that of the upper two leaves for an awned cultivar. Grundbacher (21) concluded that awns contain chlorophyll and have stomata.

Thorne (62) suggested that barley ears photosynthesize more than wheat ears because of their greater surface area. Simpson (53) studied one hundred and twenty varieties of wheat and found a high positive correlation between grain weight and the components of photosynthetic area above the flag leaf node. Nosberger and Thorne (41) suggested that the rate of photosynthesis was affected little by number of florets and that removing florets resulted in a higher photosynthetic rate by other plant parts.

Evapotranspiration

Evapotranspiration (ET) is the flux of water from the earth's surface to the atmosphere by the combined processes of evaporation of water from the soil and transpiration by plants. Evapotranspiration, therefore, is a function of soil, plant, and meteorological factors.

Penman (44) defined potential evapotranspiration as the amount of water transpired by a short green crop of uniform height that completely shades the ground and is never short of water. Under these conditions, transpiration is regulated primarily by meteorological rather than physiological factors (44, 42, 51, 64, 65, 67). In semiarid areas where water is a limiting factor for plant growth, transpiration and plant production are also functions of water availability (22, 46, 12, 60).

The rate of evapotranspiration depends on temperature, wind, and humidity gradients as well as plant characteristics which influence transpiration. Transpiration is important in decreasing the thermal stress on plants by dissipating a portion of the heat load as latent heat. Gates (19) showed that transpiration can cause plant temperatures to be lowered by 5 C in still air, by 4 C in wind at 1 mile/hr, and 2.5 C at 5 miles/hr. Ferguson, Eslick, and Aase (14) showed in a laboratory study that the transpiration rate of nonawned was less than half-awned which was less than full-awned isogenic barley ears. They also noted that full-awned ears were cooler than nonawned ears.

Transpiration and dry matter production are directly related (22, 2, 12). De Wit (12) demonstrated that the regression equation between transpiration and dry matter production varies with the climatic conditions if water availability and fertility levels are not extreme. Fritschen and Shaw (17) showed that transpiration is also related to the energy intercepted by the plant canopy. This has led to some controversy as to whether transpiration and dry matter production are a cause and effect relationship. Monteith (38) explained that net radiation largely determines transpiration and solar radiation largely determines photosynthesis. He therefore concluded that since net radiation and solar radiation are linearly related one would expect a linear relationship between transpiration and dry matter production.

Soil water tensions also influence evapotranspiration. Veihmeyer and Hendrickson (66) contend that evapotranspiration proceeds at a potential rate up to the wilting point and falls sharply thereafter. On the other hand, Thornthwaite and Mather (63) proposed a linear decline of evapotranspiration with increasing soil water tension. Pierce (47) and others propose a compromise of the two views (8). Denmead and Shaw (11) found that the transpiration rate of corn decreased at 0.3 bar soil water tension under a high transpirational demand, whereas no decrease occurred until 12 bars under a low transpirational demand. Bruce and Romken (5) illustrated that the plant growth of cotton was reduced considerably when the soil water tension was greater than 0.3 bar.

Major differences in water loss by plant species through transpiration are, therefore, a function of changing characteristics of the plant surface during the growing season, availability of water, and differences in energy absorption characteristics (17).

Net Radiation

Net radiation is defined as the difference between the incoming and outgoing radiation. It is therefore a measure of the energy retained at the earth's surface. This energy is dissipated as soil heat flux, air-sensible heat flux, latent heat flux, and photosynthesis (16). In equation form:

$$[1] \quad R_n = E + H + S + P$$

where

R_n = net radiation at the earth's surface
E = latent heat flux
H = air-sensible heat flux
S = sensible soil heat flux
P = energy stored or utilized in photosynthesis

All energy entering or residing in the system is positive and all energy leaving the system is negative.

Radiation exchange within plant communities is a function of plant surface geometry and of plant reflective and transmissive properties (32). Decker (9) showed that a tall crop (corn) retains a greater portion of the net radiation than a short crop (bluegrass). The roughness of a material also determines its heating coefficient (39). Thus, a rough surface should have a greater heat absorption capacity than a smooth surface and consequently a higher net radiation. Waggoner, Pack, and Reifsnyder (68) found that shading tobacco plants reduced net radiation which led to lower values of evaporation and a moderation of maximum air temperature. Therefore, a modification of the net radiant energy flux leads to a change in the algebraic sum of evaporation, heat transfer to the air-crop-soil volume and net photosynthesis (35).

Wind Characteristics

Wind data provide a measurement of momentum flux and are necessary in describing the boundary layer of a crop.

Horizontal wind velocity is zero at or near the ground and increases with height above the surface. The vertical gradient of windspeed can be expressed as (31):

$$[2]\quad du/dz = (1/k)(\tau_o/\rho)^{\frac{1}{2}}(1/z)$$

Integrating Equation [2] gives the logarithmic law (31):

$$[3]\quad u_z = (1/k)(\tau_o/\rho)^{\frac{1}{2}} \ln(z + z_o/z_o)$$

where

τ_o = shearing stress

ρ = density of air

z_o = roughness length

k = von Karmans constant = 0.4

u_z = wind speed at height z

z = height of anemometers measured from the soil surface

Equation [3] applies for relatively smooth surfaces. As the crop height increases, the turbulent boundary layer is raised causing the reference plane to be displaced upward. To account for this raising of the boundary layer, an effective displacement term is introduced into Equation [3]. Rewriting Equation [3], we get:

$$[4]\quad u_{z+D} = (1/k)(\tau_o/\rho)^{\frac{1}{2}} \ln(z + D/z_o)$$

where

D = z_o + d = effective displacement

z_i = the nominal heights of the anemometers

d = zero-plane displacement

A typical wind profile for wheat or barley and the aerodynamic parameters z_o, d, and D are illustrated in Figure 1. The effective

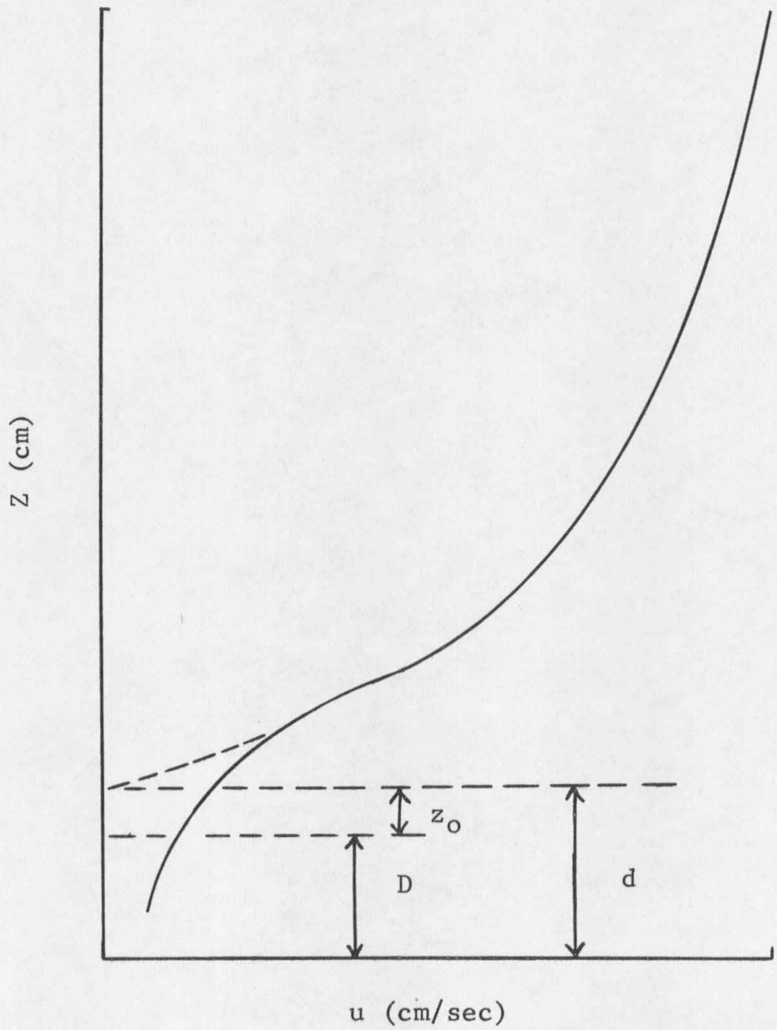

Figure 1. Schematic of wind profile indicating the aerodynamic parameters z_o, D, and d.

displacement, D, is equal to the algebraic sum of z_o and d where d is assigned a negative and z_o a positive value. Chang (8) defines the roughness length as a measure of the roughness of a surface over which a fluid flows and the zero-plane displacement as the order of the depth of the layer of air trapped among the plants. A number of conditions are necessary for the successful use of Equation [4]:

1. The shearing stress must be constant with height up to approximately 30 meters.
2. Neutral conditions must be present.
3. The highest anemometer must not be too high and lowest anemometer not too low.

Tanner (59) concluded that with a zero temperature gradient above the surface and if sufficient fetch exists, then the shearing stress is constant with height above the canopy. In determining the height of the highest anemometer, Elliott (13) has defined the height of the boundary layer by:

$$[5] \quad h = (0.75)(X)^{0.8}$$

where

h = the height of the boundary layer

X = the distance from the leading edge of the surface or canopy in question

Lemon, Stoller, and Shinn (33) stated that the zero-plane displacement is a statistical reference plane where turbulent activity appears to commence. Therefore, for a given velocity the roughness or potential turbulence above the canopy becomes greater with decreasing zero-plane displacement. Inoue (25) observed that the zero-plane displacement for 90 cm high rice varied from 35 to 90 cm and the roughness length 7 to 18 cm with varying windspeeds. Similar results have been found with corn (58) and wheat (45). Lemon, Shinn, and Stoller (33) concluded from a corn study that the roughness length and zero-plane displacement are not only a function of windspeed but also of the elasticity of the plants.

The degree of roughness of a plant surface which is related to the turbulent activity within and above the canopy becomes important in influencing heat, water vapor, and carbon dioxide fluxes (20). Gaastra (18) and Moss, Musgrave, and Lemon (40) demonstrated that an enriched carbon dioxide environment increased net assimilation even though stomatal opening and transpiration decreased. Therefore, increasing the supply of carbon dioxide to plants by increasing turbulence may increase the net assimilation even though stomatal opening and transpiration decrease. Denmead (10) and Lemon (30) concluded that turbulent mixing may be a factor in supplying carbon dioxide to an actively growing crop on sunny days.

Once the wind parameters have been interpreted, the determination of air-sensible heat flux by the aerodynamic method can be employed. In equation form, air sensible heat flux is described by:

$$[6]\quad H = \frac{\rho C_p k^2 (u_2 - u_1)(T_1 - T_2)}{(l_n((z_2 + D)/(z_1 + D)))^2}$$

where

H = air-sensible heat flux in $cal/cm^2/sec$

ρ = density of air = 0.00110 g/cm^3

C_p = specific heat of air = 0.24 cal/g/deg

T = air temperature (C) at heights z_1 and z_2

D = effective displacement (cm)

k = 0.4 (von Karmans constant)

z = heights measured from the soil surface

u = wind velocity at heights z_1 and z_2 (cm/sec)

In dryland areas where water is limiting, the partitioning of net radiation appears largely as sensible heat loss or gain to the atmosphere (22). Hanks, Gardner, and Florian (22) showed that for a 20-day period, one-third of the energy used for evapotranspiration was advective energy. Skidmore, Jacobs, and Powers (55) found that on representative and consecutive non-windy (.88 m/sec) and windy (2.26 m/sec) days the amount of potential evaporation due to the wind was 33 and 113% as much as that contributed by radiation, respectively. Bierhuizen and Slatyer (4) found that when both windspeed and carbon dioxide concentration decreased the ratio of grams water transpired to grams carbohydrate produced decreased.

MATERIALS AND METHODS

Field Study

Experimental Site

The study was conducted on a 4.1-hectare dryland site approximately 6.4 kilometers north-west of Sidney, Montana. The soil is Sprole loam and is classified as fine loamy, mixed, frigid family of Typic Agriustolls. The average yearly precipitation is 34.3 cm and the average frost-free season is 120 days.

Planting

Full-awned, half-awned, and nonawned isogenic lines of Atlas and Betzes barley (*Hordeum vulgare* L.) were planted on 50 x 50 meter plots in two replications. The barley was planted uniformly at 22.7 kg/acre in rows 18 cm apart oriented in a north-south direction on May 20 and 21, 1970. Nine isogenic lines, listed in Table 7, were planted in the south-east corner of the site. These plots were 3 x 3 meters and the rows were 30.5 cm apart. All plots received 16-48-0 fertilizer broadcast at seeding at a rate of 68.1 kg per acre.

Soil Water and Evapotranspiration Measurements

Hydraulic lysimeters of the type described by Hanks and Shawcroft (23) were located in the center of each 50 x 50 meter plot. The lysimeters were read weekly until the appearance of awns and then daily, except on weekends, until maturity.

Four neutron access tubes were located in each plot; one in the center of the lysimeter and the remaining three adjacent to the lysimeter. Soil water measurements with the neutron scattering technique were taken at the 15 and 30 cm depths and then at 30 cm increments to a depth of 180 cm. These measurements were made on May 24, June 18 and 24, July 1, 8, 15, 22, and 29, and August 13, 1970.

Evapotranspiration was then calculated from hydraulic lysimeter and neutron scattering technique data inside and outside the lysimeters.

Plant Factor Measurements

Dry matter production was determined weekly by sampling 10 random plants from each plot. The roots were cut from the plants, and the samples were then dried at 60 C for 36 hours prior to weighing.

Grain and straw yields were determined at harvest, August 10, by taking two subsamples (4 rows 3 meters long) from each plot. The barley on the lysimeters was also harvested for grain and straw yield at maturity.

Percent plump kernels was determined by taking the ratio of the weight of the kernels that did not pass through a 6/64 x 3/4 inch slotted sieve to the sample weight multiplied by one hundred. The sieve was held level and moved right to left 25.4 cm (10 inches) and then left to right to complete one cycle. The cycle was repeated 30 times.

Percent nitrogen was measured by the Kjeldahl method (26) on a finely ground 1 gram grain sample. Crude protein was estimated by multiplying %N by 5.75.

Test weights, percent plump kernels, and crude protein was determined using the grain harvested from the 3 x 3 meter plots. Dry matter production was determined from plant samples from the larger 50 x 50 meter plots.

Temperature Measurements

Temperature masts similar to those described by Lemon, Shinn, and Stoller (33) were constructed to obtain air temperature profiles within and above the canopy. The masts consisted of a series of copper-constantan thermopiles installed in a shielded plastic pipe at 10, 20, 40, 60, 80, 120, and 160 cm heights. A reference thermocouple was installed in the bottom shield. Vertical temperature differences between the heights were added to the reference temperature to obtain absolute temperatures at any of the aforementioned heights. Air was drawn across the inlets and through the central mast by a small fan mounted on top of the mast.

Air temperatures were continually recorded at 15 minute intervals after the appearance of awns.

Relative canopy temperatures were obtained with a Barnes IT3 infrared thermometer when all ears were extended from the sheath. Since only canopy temperature differences were of interest in this study, calibration for absolute accuracy with the Barnes IT3 was not made.

Net Radiation and Albedo

After the appearance of awns, net radiometers of the type described by Fritschen (16) were placed 100 cm above the canopy. Two net radiometers were alternated over the plots from July 13 to July 27, 1970. The full-awned variety was used as a check for comparison with the half-awned and nonawned varieties.

Albedo measurements were taken on July 21 with two Moll-Gorczynski type solarimeters. These solarimeters have a wavelength response between 0.28 and 2.5 microns.

Wind Data

Heat transport anemometers of the type described by Kanemasu and Tanner (27) and Beckman and Whitley cup anemometers were used to obtain wind velocity profiles. The heat transport anemometer consisted of a high resistance wire and two chromel-constantan junctions which were temperature compensated by referencing the cold junction to the ambient air stream. The mv output produced due to the difference in temperature between the heated and ambient or cold junction is a function of wind velocity. The mv output, E, from the heat transport anemometers was predicted using the equation;

$$\boxed{7} \quad E^{-1} = A + BV^{\frac{1}{2}}$$

where

V = the windspeed normal to the heated wire

A & B = constants determined from calibration

Twenty heat transport anemometers were constructed and then calibrated in a wind tunnel. In the field, mean wind velocities with the heat transport anemometers were obtained by averaging 10 point readings taken at 1.44 minute intervals. These anemometers were located 10, 20, 40, 60, and 80 cm from the soil surface.

With the cup anemometers, mean wind velocities were obtained over 15 minute periods at heights of 60, 80, 120, and 200 cm from the ground.

Windspeed and direction was recorded routinely on a strip chart recorder at 1.5 meters from the ground.

<u>Data Collecting</u>

An instrument trailer located on the east side of the site housed the recording equipment. The data were recorded on a teletype which provided both a printed copy and a computer compatible paper tape. This system provided a completely automatic recording of records under the control of a digital clock. Net radiation, windspeed (heat transport anemometers), and air temperature profiles were thus recorded by the data acquisition system.

Laboratory Study

<u>Carbon Dioxide Assimilation</u>

Full-awned and nonawned isogenic lines of Atlas and Betzes barley were planted in the greenhouse on March 29, 1970. At anthesis the ears were cut from the plants and placed into test tubes filled with water. After four hours, the individual ears were placed in an assimilation chamber and carbon dioxide assimilation rates were determined.

The assimilation chamber, constructed from plexiglass, consisted of an inner chamber and an outer chamber. The inner chamber contained the ear and allowed for circulation of air. The outer chamber served the purpose of a water jacket to maintain a constant temperature of 22.5 C within the inner chamber. The experiment was conducted in a constant temperature room set at 22.5 C.

The ear was held in the chamber by placing the portion of the stem directly below the ear into a split rubber stopper and then sealing the stopper with bees wax. Compressed air of known CO_2 concentration was passed through a drying tube (magnesium perchlorate), into the chamber, and then through a flow meter before entering the carbon dioxide infra-red analyzer. The flow of air through the chamber was regulated at 0.5 l/min.

A light intensity of 5.43×10^{-3} cal sec^{-1} cm^{-2} was obtained by using a fresnel lens above and mirrors on either side of the ear chamber; thus, concentrating the light from the Lucalox lamp toward the ear. A cold water bath was placed between the light source and the ear chamber and removed a large part of the infrared light energy.

The difference in the CO_2 concentration (ppm) of the air entering and leaving the ear chamber was recorded for each ear. The number of awns and kernels per ear were counted and recorded.

RESULTS AND DISCUSSIONS

In general, the 1970 crop season was characterized by considerable variation in monthly precipitation and temperatures. The early stages of the crop season (April and May) were characterized by low temperatures and above average precipitation. Following seeding the weather changed abruptly marking the beginning of a hot and extremely dry period. As a result, grain yields fell slightly below normal; however, due to precipitation in early July, kernel development and test weights were above average. Lack of tillering appeared to be the main factor contributing to the low grain yields observed in 1970.

During the flowering stage of plant development, Atlas, a six-row cultivar, became seriously infected with ergot. Betzes, a two-row cultivar, showed less severe signs of ergot disease possibly because its development was one week behind that of Atlas. No other plant diseases were observed in 1970.

<u>Aerodynamic Characteristics of Full-Awned and Nonawned Atlas</u>

A knowledge of wind velocity gradients in and above a plant canopy are necessary in determining the fluxes of heat, water vapor, and carbon dioxide by the aerodynamic approach. In this study wind velocity gradients were used to graphically determine the aerodynamic parameters (roughness length, zero-plane displacement, and effective displacement) in full-awned and nonawned Atlas.

Typical wind profiles in and above full-awned and nonawned Atlas canopies are illustrated for July 8 and 20, 1970, in Figures 2 and 3, respectively. At this time the barley was in the flowering stage and had reached maximum plant height; both the nonawned and full-awned Atlas were 56 cm high to the top of the heads, and the awns accounted for an additional 9 cm on the full-awned canopy for a total height of 65 cm. On July 8, the mean wind velocity at 200 cm was 349 cm/sec and on July 20, 536 cm/sec. A comparison of the horizontal wind velocities indicated that the full-awned canopy acted as a greater sink for the horizontal wind momentum than the nonawned canopy (Figures 2 and 3). Duncan's multiple range test showed this to be significant (P = .05) at the 60, 80, and 120 cm heights on July 8 and at the 40, 60, and 120 cm heights on July 20. The wind velocity at heights 10, 20, and 200 cm for the respective canopies were not significantly different (P = .05). Apparently the awns, because of their large surface area, created a resistance to the horizontal momentum of the wind explaining the above phenomenon.

From graphical techniques explained in detail by Lemon (31), the wind profiles were analyzed for the functional relationships of roughness length, zero-plane displacement, and effective displacement. Roughness length is a function of plant height, surface geometry, plant density, and plant elasticity. Plant density was assumed to be similar, and variation in roughness length between full-awned and nonawned Atlas was attributed to one or all of the other factors. On July 8 and