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Turbulence over wheat crop and bare soil surfaces on a day at Hissar

O. P. BISHNOI, V. UMAMAHESWARA RAO and GURMEET SINGH

Haryana Agricultural University, Hissar

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सार — मुख्य वायुगतिकी विशेषताएं, जैसे कि संवेग का विनिमय, वायुगतिक प्रतिरोध, भंवर विसरणशीलता, ऊर्जा का क्षय और भंवर के आकारों का गेहूं की फसल के वितान और नग्न मृदा की सतह पर मूल्यांकन दिखाया गया है। फसल की सतह पर प्रक्षोभ के लक्षणों ने भंवरों के आकार के और संवेग के स्थानान्तरण को विशेषरूप से प्रभावित किया जिसने बदले में वाष्पोत्सर्जन और फसल की वृद्धि को प्रभावित किया।

ABSTRACT. Important aerodynamic characteristics such as exchange of momentum, aerodynamic resistance, eddy diffusivity, dissipation of energy and eddy sizes evaluated over wheat crop canopy and bare soil surface are presented. The turbulence features over cropped surface significantly affected the size of eddies and transfer of momentum which in turn affected the evapotranspiration and crop growth.

1. Introduction

The interaction between turbulence and vegetative canopies has not been firmly substantiated in the literature. The turbulence mixing of air plays an indispensible role in creating microclimates which accounts for the transfer of water vapour, heat and carbon dioxide between crops and atmosphere. Tan and Long (1963) and Inoue (1963) developed theories on crop turbulence. Uchijima and Wright (1964), Wright and Lemon (1966) analysed the turbulence characteristics in maize crop. Baines (1972) carried a similar study for wheat crop. These studies present inadequate knowledge of turbulence and generation of eddies above and within the crop canopies to understand the transfer mechanisms. Cionco *et al.* (1963) suggested that turbulence was essentially constant with height for an idealized canopy. Eddy size plays an important role in contributing heat and momentum fluxes and, therefore, its quantification in crop and over bare soil is very essential. In the present study turbulence characteristics have been presented over wheat and bare soil surface.

2. Experimental details

Wind profile measurements were made over wheat crop and bare soil at Hissar (29° 10′ N, 75° 46′ E) from 0730 LMT (local mean time) to 1630 LMT at hourly intervals for 10 minutes time centred over the hour on 11 April 1984. Wheat crop was at maturity stage with an average height of 104. 4 cm. A sufficient fetch ratio of 1:100 (crop height : effective horizontal cropped distance on the windward side from field edge to the observation location) was available for obtaining the wind profiles. Two separate RIMCO-6 cup miniature sensitive anemometers (Selbys Ltd., Australia) were used simultaneously having starting speed of 0.2 m/sec, turning circle diameter of 100 mm and overall height of the anemometer was 108 mm. The anemometers were having accuracy of ± 1 per cent of mean value between 2 and 8 m/sec. Hourly mean wind speeds were recorded with pulse generating counters at 50, 60, 80, 120, 200 and 360 cm height above the ground. Adjustable extension arms which fit standard anemometer holder were used to maintain the different levels.

3. Aerodynamic characteristics

The Richardson number (R_i) was estimated using Webb's (1970) method as :

$$R_i = \frac{g\,(\theta_2 - \theta_1)}{\theta\,(u_2 - u_1)^2}\ 10^{-2}\, z.\ \ln\left(\frac{z_2}{z_1}\right) \qquad (1)$$

where,

g=acceleration due to gravity

θ=temperature at height z cm in °K

$\theta_2 - \theta_1$=temperature difference in °C between z_2 and z_1 levels

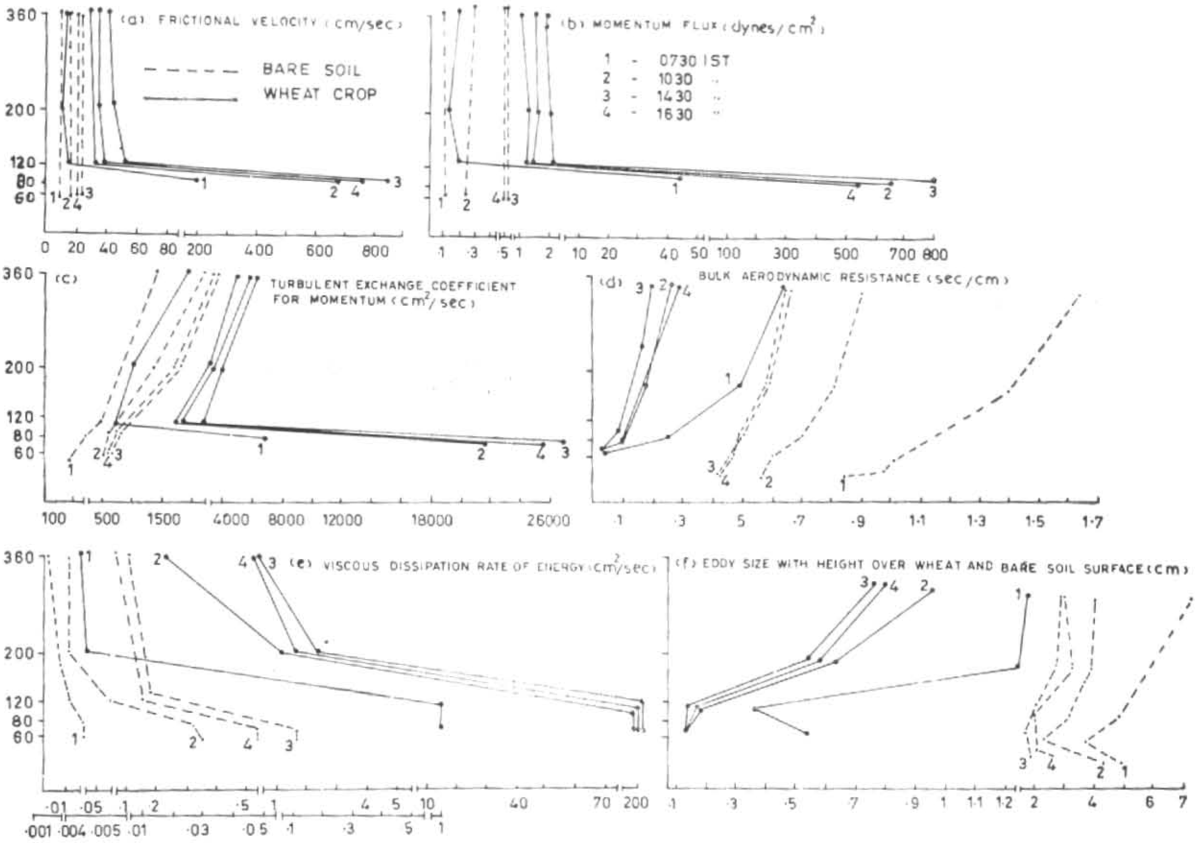
$u_2 - u_1$=wind speed difference in m/sec between z_2 and z_1 levels

Using Eqn. (1) Richardson number was estimated for all hourly values which varied from 0.0027 to 0.00008. Mohin-Obukhov length (L) was calculated from Richardson number R_i.

As $R_i << \theta$, therefore, $L = z/R_i$ (2)

The wind profile was well described by logarithmic law under neutral conditions as :

$$u = \frac{u^*}{k}\ \ln\left(\frac{z-d}{z_0}\right) \qquad (3)$$



Figs. 1(a-f). Distribution of momentum flux, eddy diffusivity, rate of viscous dissipation, size of microscale eddies etc

and under non-neutral conditions :

$$u = \frac{u^*}{k} \left[\ln \left(\frac{z - d}{z_0} \right) + 5 \left(\frac{z - d - z_0}{L} \right) \right] \quad (4)$$

where u^* is frictional velocity, k is von Karmon constant, u is horizontal wind speed at height z cm from ground, d is zero plane displacement and z_0 is roughness parameter.

The momentum flux at the top of the crop (τ) was estimated using the logarithmic law of Prandtl for wind velocity profiles as :

$$\tau = u^{*2} \rho \quad (5)$$

where ρ is density of air.

The eddy diffusivity or the turbulent exchange coefficient for momentum, K_m, to understand the loss of momentum to leaves and stalks in different crop foliage layers affecting the size of eddies, was determined at different levels above ground using the expression :

$$K_m = k\, u^* (z - d) \quad (6)$$

The bulk aerodynamic resistance, r_{am}, to the transfer of momentum from the level z in the atmosphere flow over wheat crop was computed as :

$$r_{am} = u / u^{*2} \quad (7)$$

The rate of viscous dissipation of energy (E) and size of eddies (λ) were determined from Baine's (1972) expression in different air layers as :

$$E = \frac{\tau}{\rho} \frac{d\,u}{d\,z} \quad (8)$$

$$\lambda = 15 \left(\frac{v^3}{E} \right)^{\frac{1}{4}} \quad (9)$$

where v is kinematic viscosity of air and ρ is density of air. Mac Cready (1953) also asserted that λ corresponds to the size of eddy below which 90 per cent of viscous dissipation occurs.

The mixing length (l) and drag coefficient of wind (c_d) on the surface were computed as :

$$l = k\,(z - d) \quad (10)$$

$$c_d = \left(\frac{u^*}{u} \right)^2 \quad (11)$$

4. Results and discussion

(i) Crop aerodynamics

The wheat crop attained maturity stage by 11 April 1984 with interlocking leaves projection upwards. This vertical projection influenced the aerodynamics of the crop. The average value of z_0 and d was 13.6 cm and 65.8 cm respectively for the crop height of 104.4 cm. Similar results have been reported by several others while working with field crops. Inoue (1963) reported d=60 cm, z_0 =19 cm in paddy of height 90 cm; Uchijima and Wright (1964) reported d=85 cm, z_0=5 cm in corn of height 140 cm; Cowan (1968) reported d=0.64 h; Tanner and Pelton (1960) reported z_0=0.13 h for field crops (where h is crop height), Inoue *et al.* (1963) reported d=50 cm, z_0=10 cm for wheat crop of height 130 cm.

(*ii*) *Turbulence characteristics*

The distribution of momentum flux, eddy diffusivity, rate of viscous dissipation, size of microscale eddies are presented in Figs. 1 (a-e) for wheat and bare soil surfaces.

The frictional velocity and shearing stress decreased slowly with height above the crop canopy, but attained enormously high values inside the crop canopy layers due to turbulence generated by the roughness of the crop surface [Figs. 1 (a & b)]. However, over the bare soil no variation was observed. The eddy diffusivity increased with height over the bare soil surface due to sharp change in frictional velocity, but it decreased with crop height within the crop canopy, however, there was increase with height above the canopy-air interface over the wheat crop. The transition of decreasing to increasing trend took place at the crop height due to rapid change in the frictional velocity. In the turbulent boundary layer the momentum transfer coefficient was observed to be dependent upon the turbulent wind parameters u^*, τ.

The computed values of u^*, τ, K_m and E and their changes with time are indicative of the type of surface roughness, elasticity and cavities formed in between rows of the wheat canopy. Quantitatively these parameters are lesser over bare soil surface as compared to those over the wheat crop. It is remarkable to observe that shearing stress on the wheat crop is also double and the turbulent exchange coefficient (K_m) is four times as compared to their corresponding values over the bare soil surface. These results are consistent with Uchijima (1962 a & b).

Values of r_{am} are lesser over cropped surface as compared to the soil surface and this created higher dissipation rate over cropped surface in order to generate eddies of smaller size in the lower air layers below the crop canopy height. With the sharp and abrupt change in the turbulent parameter values, the eddies breakdown over the crop surface due to interaction with the foliage and smaller eddies are generated in lower air layers inside the canopy. There is lesser breakdown of eddies and even larger eddies are available over bare soil surfaces.

Viscous dissipation rate (E) decreases with increasing height over bare soil surface and over the crop surface, however, within the canopy it was more or less constant. The decrease of viscous dissipation rate is related to the corresponding decrease of momentum flux with increasing height. Similar trend was recorded in the data of Uchijima and Wright (1964) for maize. Viscous dissipation rate values increase with decreasing height and reach to a maximum at canopy air boundary. On the bare soil surface E values decrease with height and attain much lower values as compared to those over the wheat crop. However, above the canopy these values become closer to each other because the boundary layer effects due to wheat canopy vanishes slowly and slowly with increasing height. However, up to 360 cm boundary effects exist—the level up to which the observations have been recorded. These results are consistent with the results of Uchijima and Wright (1964) for maize and Baines (1972) for wheat.

TABLE 1

Drag coefficient (c_d) and mixing length (l) at different levels

Height (cm)	c_d		l (cm)		
	Wheat	Bare soil	Wheat	Bare soil	Soybean (Perrier *et al.* 1972)
360	0.018	0.0053	120.6	147.6	118.6
200	0.032	0.008	55.0	82.0	54.1
120	0.087	0.01	22.0	49.2	25.6
80	74.5	0.01	5.8	32.8	7.25
60	—	0.011	-	24.6	0.98
50	-	0.012	—	20.5	0.82
Crop ht (cm)	104.4		104.4		106.0

Over the bare soil surface, the eddies were of larger size than over the cropped surface because with turbulence exchange of energy the eddy sizes are maintained and breakdown of eddies is less in comparison with those in crop. However, the eddy size decreased with height and attained lowest value at 80 cm above the ground surface. With further increase in height, eddies were observed to increase probably due to the superimposition of reflected eddies leading to stationary eddies with the lowest eddy size at 80 cm above the bare soil surface. At 0730 LMT the eddies were of bigger size with minimum of 3.8 cm eddy size, but at 1430 LMT the eddies were of lesser size with lowest value of 1·5 cm at 80 cm above the surface because of the breakdown of eddies during day time. In wheat crop eddies were still smaller in size due to the breakdown of eddies. For examples eddy size at 80 cm crop heights, were 0.36 cm and 0.15 cm at 0730 and 1430 LMT respectively. Uchijima and Wright (1964) has also reported similar results with eddy size of 0.4 cm at canopy height and also showed increase in eddy size with decreasing height in crop.

Eddy size decreased with height at the surface layer and reached lowest at the canopy air interphase. Further, eddy size increased with height above the crop canopy. The turbulent exchange was much higher in upper air layers and provided turbulent energy for increase of the eddy size. Further, the size of these eddies decreased with the decrease of turbulent exchange coefficient towards the ground surface. The dependence of turbulent exchange coefficient (K_m) on the frictional velocity implies that eddies mix at the same rate with which the wind speed increases. The eddy structure of airflow within the crop is regulated by the eddies available at the top of the crop, *i.e.*, the eddies are generated by the breakdown of large scale atmospheric turbulence in the crop boundary layer through shear flow.

Comparison of momentum transfer coefficient and mixing lengths over two surfaces shows that the lower portion of the boundary layer is the critical region where both the parameters vanish at $z=z_0+dh$, the effective displacement height. Because of the crop cavity flow regime between the rows, it is inconceivable that the momentum transfer coefficient would disappear as predicted by the extrapolated log-law relation, but the small portion of vertical component of momentum is continuously transferred into crop cavity which is responsible for continuous generation, deformation and destruction of eddies towards the ground surface so that energy of eddy motion is ultimately degraded to kinetic energy (E) of individual molecules. These eddies are responsible for the transfer of heat, water vapour and carbon dioxide in the lower canopy layers. Further, scale of canopy eddies are influenced by environmental factors such as plant height, zero plane displacement and leaf arrangements, etc.

The drag coefficient values were much higher in the cropped field as compared to the bare soil surface at different heights. This parameter presents the resistance offered by the roughness conditions to wind speed at different heights. Over wheat cropped surface the drag coefficient values increased with decreasing height and reached a maximum value at canopy-air interface. In the canopy layer, the drag coefficient value was tremendously high due to the rapid increase in air resistance generated due to plant leaves. However, over the bare soil surface, the drag coefficient values were 4 to 10 times lesser than the corresponding values over wheat crop at different heights. In the lower air layer near the ground, the drag coefficient was of the order of 0.01 as compared to 74.1 at the wheat canopy-air interface (Table 1). Goldstein (1938) also reported this trend and Perrier *et al.* (1972) working with soybean of same height reported c_d values from 0.03 to 0.047. Mixing length values over wheat surface were lesser as compared to the bare soil surface because of breakdown of eddies. However, the decrease in mixing length over wheat cropped surface was much faster as compared to the decrease in mixing length over bare soil surface. At 80 cm height, just below the canopy air interface, mixing length was of the order of 5.8 cm as compared to 32.8 cm mixing length over bare soil surface at the same height. Nakagawa (1956) also reported mixing length of 3.8 cm to 16.5 cm inside the paddy crop. The eddy sizes are responsible for generating the microclimate inside the crop canopies.

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