植物群落内の風速分布について

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著者	斎藤, 隆幸
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On the Wind Profile within Plant Communities

Takayuki SAITO

1. Introduction

Although the wind within plant communities is of the basic importance in describing the problems of exchange of matter and energy between plants and air, the analysis of the wind within plant communities seems to be insufficient both theoretically and experimentally.

Some approaches were made to such problems of wind profiles and diffusivity within a wheat field by Penman and Long (1960). Vertical distribution of turbulent diffusivity within plant communities was estimated by use of energy balance method by Saito (1962) and Uchijima (1962 a). Some problems of wind profile and momentum flux, etc. in plant communities was described by Uchijima (1962 b). Recently these problems have been also discussed by Inoue (1963), Isobe (1964), and Uchijima and Wright (1964).

In the present paper, the author intends to explain the way in which the wind profile within plant communities is built up.

2. On the characteristics of observed wind profiles within a crop

An analysis of wind profile was carried out by use of two data, one presented by Stoller and Lemon (1961) on a corn field and the other by Penman and Long (1960) on a wheat field.

(a) On the wind profiles within a corn field

Several wind profiles above and within the corn field given by Stoller and Lemon (1961) are shown in Fig. 1-1 in the normalized form.

These profiles are in good agreement with each other. From this agreement it is concluded that the gradient of wind velocity at a height within a field is proportional to the reference wind velocity, that is

$$\frac{du}{dz}=p(z)\cdot u, \tag{1}$$

where $p(z)$ is a proportion factor, independent of wind velocity. Provided that the boundary condition is given by $u=u_H$ at the crop surface $z=\mathrm{H}$, we have

$$u=u_H e^{-\int_z^H p dz} . \tag{2}$$

The value of p is computed from observed wind profiles, and shown in Fig. 1-2.

(b) On the wind profiles within a wheat field

The data in the period 12-19 June 1957 by Penman and Long were used. The

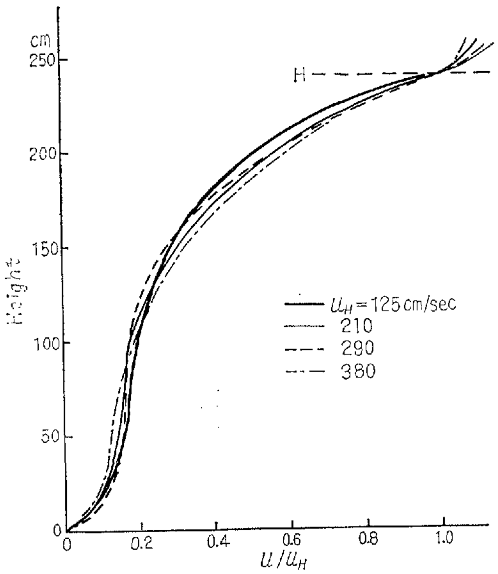

Fig. 1-1 Normalized wind prfiles within a corn field. H: crop surface.

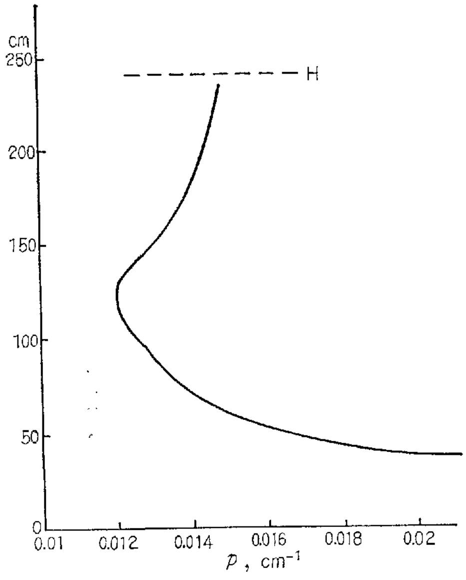

Fig. 1-2 Variation of p with height within a corn field.

observed wind velocities at the crop surface cover the range from 30 to 260 cm$\cdot$sec^{-1}. Two typical profiles, one for a calm weather in 8–12 hr. 14 th day and another for a windy weather in 8–12 hr. 12 th day, are selected and their normalized wind profiles are shown in Fig. 2–1. A clear distinction is seen between these two profiles. This feature is different from that of the case of the corn field mentioned above. On this point Penman and Long state that wind profiles in the wheat have

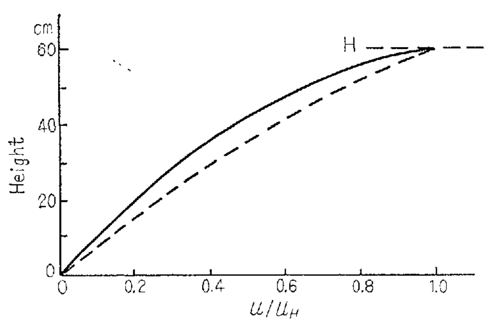

Fig. 2-1 Normalized wind profiles for calm, and moderate wind within a wheat field. Full line: $u_H=240$ cm$\cdot$sec^{-1}, Broken line: $u_H=55$ cm$\cdot$sec^{-1}, H: surface.

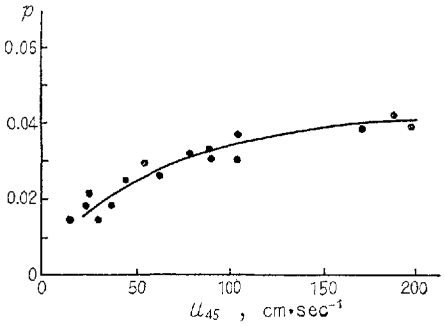

Fig. 2-2 Relation between p and u at $z=45$ cm within a wheat field.

a completely different shape respectively in calm and windy weather, and that however near the ground the absolute wind speed tends to be constant because the crop behaves to present the effect of self-sealing. If the relation between the wind velocity and its gradient is written as a following equation

$$\frac{du}{dz}=p(z\cdot u)\cdot u, \qquad (3)$$

$p(z\cdot u)$ must be a function depending both on height and on wind velocity, because the normalized profile depends both on the wind velocities at the crop surface and on the height, too. The value of p can be computed from observed wind profiles. In order to see the change of shape of normalized wind profiles with the wind velocity, the value of p at $z=45$ cm was plotted against the wind velocity in Fig. 2-2. Owing to the lack of observations near the ground, p at the lower level has not been computed here. From the evidence that the value of p becomes nearly constant for the wind velocity exceeding about 100 cm•sec^{-1}, it may be concluded that the change of normalized wind profiles is observed only under light wind conditions of the strength below about 100 cm/sec at the crop surface.

Since $p(z\cdot u)$ in eq. (3) is a function of z and u, it seems difficult to express the wind profile by a simple formula. However, the difference of normalized wind profiles for different wind velocities at crop surface is relatively small, then the profile can be expressed approximately by the same formula as eq. (2) such as

$$u=u_He^{-\int_z^H pdz}.$$

3. Explanation of build-up of wind profile

In this section eqs. (1) and (3) are explained semi-empirically. Since the edge effect on wind within a crop at the observational site seems to be negligible, it may be plausible to suppose that wind blowing over the crop surface causes the eddy shearing stress within crop giving rise to the dawnward transport of momentum by vertical motion of eddy through the space between leaves and stalks. Taking the presence of leaves and stalks into account, the magnitude of momentum flux averaged over the horizontal plane can be expressed by the following equation

$$\tau=\rho\cdot(1-F')\cdot\overline{w'\cdot u'}\ , \qquad (4)$$

where F' is horizontal projected area in percent of leaves and stalks involved within unit depth per unit space area, w' and u' are eddy velocities. If the following relations are assumed

$$w'\propto u' \text{ and } (u'^2)^{\frac{1}{2}}\propto u, \qquad (5)$$

we get

$$\tau=\rho\cdot(1-F')\cdot a\cdot u^2, \qquad (6)$$

where a is a proportion factor, assumed to be a function of height. On the other hand, momentum flux within crop decreases with distance from the crop surface. The rate of change in momentum flux is equal to the drag force offered by plants giving rise to

$$\frac{d\tau}{dz}=\rho\cdot C\cdot F\cdot u^2, \tag{7}$$

where F is the total area of leaves and longitudial section of stalks per unit volume and is a function of height, and C is the drag coefficient of plant depending on the height. From eqs. (6) and (7), we get

$$\frac{du}{dz}=\frac{1}{2a(1-F')}\left[C\cdot F-\frac{d}{dz}\left\{a\cdot(1-F')\right\}\right]\times u\ .$$

Denoting

$$\frac{1}{2a\,(1-F')}\left[C\cdot F-\frac{d}{dz}\left\{a\,(1-F')\right\}\right]=p, \tag{8}$$

we have

$$\frac{du}{dz}=p\cdot u\ . \tag{9}$$

If C is a function of height independent of wind velocity, p in eq. (8) or (9) becomes also a function of height only. Then eq. (1) or (2) can be explained. In other words, when observed wind profiles are expressed by an exponential function, a drag coefficient of plants is supposed to have a constant value independent of wind velocity.

Exponential wind profile within a wheat field is also obtained empirically by Inoue (1963),

$$u=u_He^{-\alpha(H-z)},\qquad \alpha=\text{const.}\ ,$$

which can be deduced from the above consideration under the condition that a, F, F′ and C are all independent of z and u. However, a condition α=constant through the all height does not seem to be satisfied in the general case.

Next, in order to explain eq. (3), p in eq. (8) or (9) must be a function depending not only on height but also on wind velocity. The dependence of p in eq. (8) or (9) on wind velocity is required to have the same tendency as that shown in Fig. 2-2. To satisfy these reqirements, we assume that C in eq. (8) increases with wind velocity, having the same tendency as p against wind velocity as shown in Fig. 2-2. If the assumption for C in eq. (8) as mentioned above is used, the build-up of wind profile within a wheat field can be explained. That is, we can explain the change of normalized wind profile for a calm and for a windy weather from the view of increasing of drag coefficient with wind velocity. An increasing tendency of drag coefficient of wheat is also shown by Isobe (1964).

Contrary to the decreasing tendency of drag coefficient of a rod placed in laminar flow, it is suggested here that the drag coefficient of wheat under field condition increases with wind velocity. The suggestion may be supported by the fact that the space between leaves is very narrow under the field condition and, in addition, leaves of wheat may easily flutter in wind. As mentioned before, constancy of drag coefficient of corn has been assumed to explain the wind profile within corn field. The assumption may come from the fact that the corn leaves flutter rather slowly and that the space between leaves is far larger than that of wheat field allowing the passage of eddy more easy than the case of wheat field. On the other hand, Uchijima suggested that the drag coefficient of corn decreases slightly with increasing wind velocity under field condition. From these considerations it seems possible to say that the difference in the wind dependence of the drag coefficient may be caused by the difference in both the leaf fluttering and the plant density.

In a further research it is desired to establish experimentally the relation between drag coefficient of the plant and wind velocity under field conditions.

4. Relation between turbulent diffusivity and wind velocity

If turbulent diffusivity K is defined by

$$\tau=\rho\cdot(1-F')\cdot K\frac{du}{dz}, \qquad (10)$$

we have

$$K=\frac{a}{p}\cdot u\ . \qquad (11)$$

Though the value of a is not known, from eq. (11) the variation of K with u at a level can be inferred by use of the observed value of p and u. Since p is independent of u for corn field as mentioned before, K within corn field increases in proportion to wind velocity. For the wheat field, using the observed relation between p and u, the dependence of K on u can be also inferred.

From eq. (11) it is seen that the K-profile is obtained with the profiles of a, p and u. Since a-profile is not known here, then the K-profile is not obtained from the observed wind profile only. However, if a is assumed to be a constant with height, the K-profile is roughly estimated with observed profiles of p and u, using turbulent diffusivity at crop surface which is computed from well-known formula of $K=\kappa\cdot u_*\cdot(z-d)$. Fig. 3 shows the K-profile within a corn field by the rough estimation.

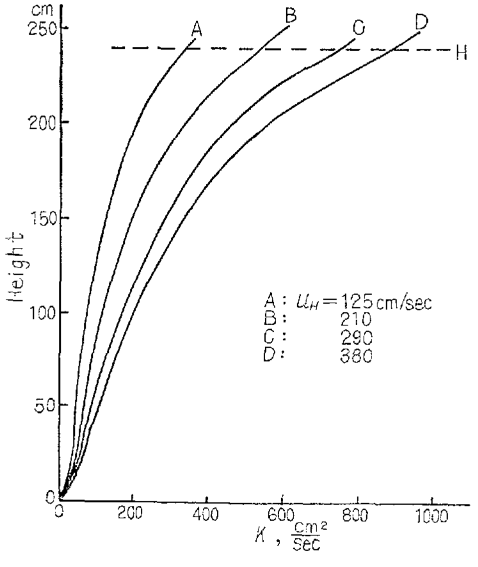

Fig. 3 Computed turbulent diffusivity profiles.

Conclusion

An analysis of wind profile within a crop field was carried out for corn field and for wheat field. From the evidence that normalized wind profiles within a corn field are in good agreement with each other for different wind velocity at the crop surface, it is seen that the wind profile within corn field can be expressed by an exponential formula. The exponential formula was explained semiempirically by use of some assumptions.

On the wind profile within a wheat field, the exponential formula can be also used approximately. It is found that the normalized wind profiles have different shapes due to the strength of wind velocity at crop surface. The cause of these differences in shape of normalized wind profile can be explained taking the increasing drag coefficient of plant with wind velocity into account.

The dependence of turbulent diffusivity on wind velocity was discussed. It was shown that the turbulent diffusivity within plant communities depends upon the profiles of a, p and u.

Acknowledgments

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References cited

1) Inoue, E., 1963: On the Turbulent Structure of Air Flow within Crop Canopies. J. Met. Soc. Japan, Ser, II, 41, 317—326.

2) Isobe, S., 1964: Zero-plane Displacement in Relation to Extinction of Momentum Flux in Crops. Bull. Nat. Inst. Agri. Sci., Series A. 11, 1—18.

3) Penman. H. L, and I. F. Long., 1960: Weather in Wheat. Quart. J. R. Met. Soc. 86, 16-50.

4) Saito, T., 1962: On Estimation of Transpiration and of Eddy-Transfer Coefficient within Plant Communities by Energy Balance Method. Jour. Agri. Met. Japan, 17, 101-105. (in Japanese with English summary).

5) Stoller, J. and E. Lemon., 1963: Photosynthesis under Field Conditin. VII. Turbulence Characteristics of the Air within and above the Crop. Production Res. Rep. No. 72, U.S.D.A. (in press).

6) Uchijima, Z., 1962 a: Studies on the Micro-Climate within the Plant Communities. (1) On the Turbulent Transfer Coefficient within Plant Layer, Jour. Agri. Met. Japan, 18, 1-9. (in Japanese with English summary).

7) ————, 1962 b: Studies on the Micro-Climate within Plant Communities. (2) The Scale of Turbulent and the Momentum Transfer within Plant Layers. Jour. Agri. Met. Japan, 18, 58-65, (in Japanese with English summary).

8) ————, and J. L. Wright, 1964: Experimental Study of Air Flow in a Corn Plant-Air Layer. Bull. Nat. Inst. Agri. Sci., Series A, 11, 19—66.

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斎藤隆幸

摘要

植物群落内では裸地上とはことなった群落特有の風速垂直分布が成立するものである。群落内に於ける植物体と空気との間の水蒸気・炭酸ガス・熱等の交換を論ずる場合には，当然それに作用する風の作用を考慮しなければならない。ここでは群落特有の風速分布がどのようにして成立するかを考えてみた。

Stoller および Lemon (1963) によって与えられたとうもろこし畑内の風速のことなる4つの風速分布を normalize する（畑の上面に於ける風速を1とした風速の相対的分布をつくること）と，それらすべての normalize された分布がどの高さでもよく一致した (Fig. 1-1)。このことは群落内のどのような高さの風速勾配も，その高さの風速に比例することを意味するものであり，したがって次式が得られる。

$$\frac{du}{dz}=p(z)\cdot u$$

$p(z)$ は比例係数で，高さによっては変るが，風速によっては変らない。観測より得られた p の分布が Fig. 1-2 に示されている。

畑の上面に於ける風速 u_H と畑の内部の風速 u との関係は上式を積分することによって得られる。即ち

$$u=u_H e^{-\int_z^H p\,dz}$$

上式より今扱ってきたとうもろこし畑内の風速分布は簡単に指数函数をもって表わし得ることが分った。植物体の抵抗係数が高さによっては変るが風速によっては変らないという仮定を用いて上式の成立を理論的にみちびくことができた。

次に Penman および Long (1960) による小麦畑内における風速分布の data を前と同様の方法で整理してみると，Penman および Long によって指摘されたように，畑の上面における風速の大小によって，normalize された風速分布の形がことなってくる (Fig. 2-1)。特にその傾向は風速の弱い場合に著しい。従って前にのべたとうもろこし畑の場合のように簡単な指数公式を以て分布をあらわすことはできない。（但し normalize された分布の風速によるちがいはそれ程大きいものではないから近似的には，指数公式をもって表わすことはできる。）風速によって normalize された分布がちがうという現象を小麦の抵抗係数が風速と共に増加するという仮定を用いて説明することができる。この仮定は前のとうもろこし畑の場合に抵抗係数に対して使用された仮定とはことなるものであるが，葉の風によるゆれ方や，植物の植え方の粗密の度合によっては，抵抗係数の風速による変り方にこのような相違がおこることもあり得るのではないかと思われる。

最後に畑内の拡散係数が風速および高さによってどのように変るかが吟味された。