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Studies on the drying of marshy and heavy clay soil ground by means of vegetations—Changes in soil water caused by evapotranspiration of *phragmites communis*—

Akira KAMIO
(Laboratory of Reclamation and Melioration, Faculty of Agriculture, Yamagata University, Tsuruoka 997, Japan)

Introduction

A very important problem in promoting land reclamation in the Hachirogata Central Polder is how to hasten the drying of the marshy and heavy clay soil ground, under the poor meteorological conditions of the Japan Sea coast[1].

In the present paper, a few comments are presented on the process of drying the marshy and heavy clay soil ground and its relationship to characteristics of meteorological factors, growth of P. *communis* and changes in soil water through transpiration of P. *communis*, etc. in Hachirogata Central Polder.

Study sites and Methods

Two study stations, G_{13} and G_{14}, were selected as typical mixed and dense stands of P. *communis* community, respectively (see previous paper[2]). G_{14} station that had been left in this natural condition since the initial land drainage was completed in spring of 1965, and where dense stands of P. *communis* grow annually. The level of ground-water table was measured with the same method as described in the previous paper[2] from late April to early December in 1977. Meteorological data of Hachirogata Central Polder were obtained from Hachirogata New Community Development Corporation[3].

Plant height and leaf area of P. *communis* were measured at intervals of about twenty or thirty days. Two quadrats of 0.5 m × 0.5 m were sampled at random at point (a) on G_{14} station (Plant height and leaf area were obtained as the mean value of the two quadrats). The productive structure was investigated in one quadrat of 1 m × 1 m by the stratified clip method. Plant samples are dried to a constant weight at 80 ℃ to weigh dry weight.

In late October, 1977, the current year's horizontal rhizomes were carefully dug up by a planting trowel from a depth of about 30 cm at point (a) in G_{14} station. Next, the previous year's rhizomes and roots were more carefully dug up following to the current year's horizontal rhizomes, and in young order, the rhizomes were dug up in the same way.

Soil moisture suction was measured by a tensiometer (Ikeda S-7 type) at depths of 5, 10-15, 20-25, 30-35, 50 and 70 cm at point (a) in G_{14} station and at depths of 10, 20, 30, 40, 50 and 70 cm at point (e)[4] in G_{13} station from July to August in 1973 respectively.

Three undisturbed soil cores at various depths were sampled at point (a) in G_{14} station and at point (d) after land grading (bare ground) in G_{13} station respectively. The samples were dried to equilibrium in an oven at 105 ℃ to obtain mean value of soil water content.

Evapotranspiration in dense stands of P. *communis* was measured during a period of clear weather by determining changes in soil water storage at point (a) in G_{14} station in late July.

Results and Discussion

1. Seasonal changes of meteorological factors in Hachirogata Central Polder area

Fig. 1 indicates the seasonal changes of meteorological factors (monthly mean values for the period from 1966 to 1974) in the central polder (meteorological observation was not made in 1964 and 1965). The following are the main characteristics of

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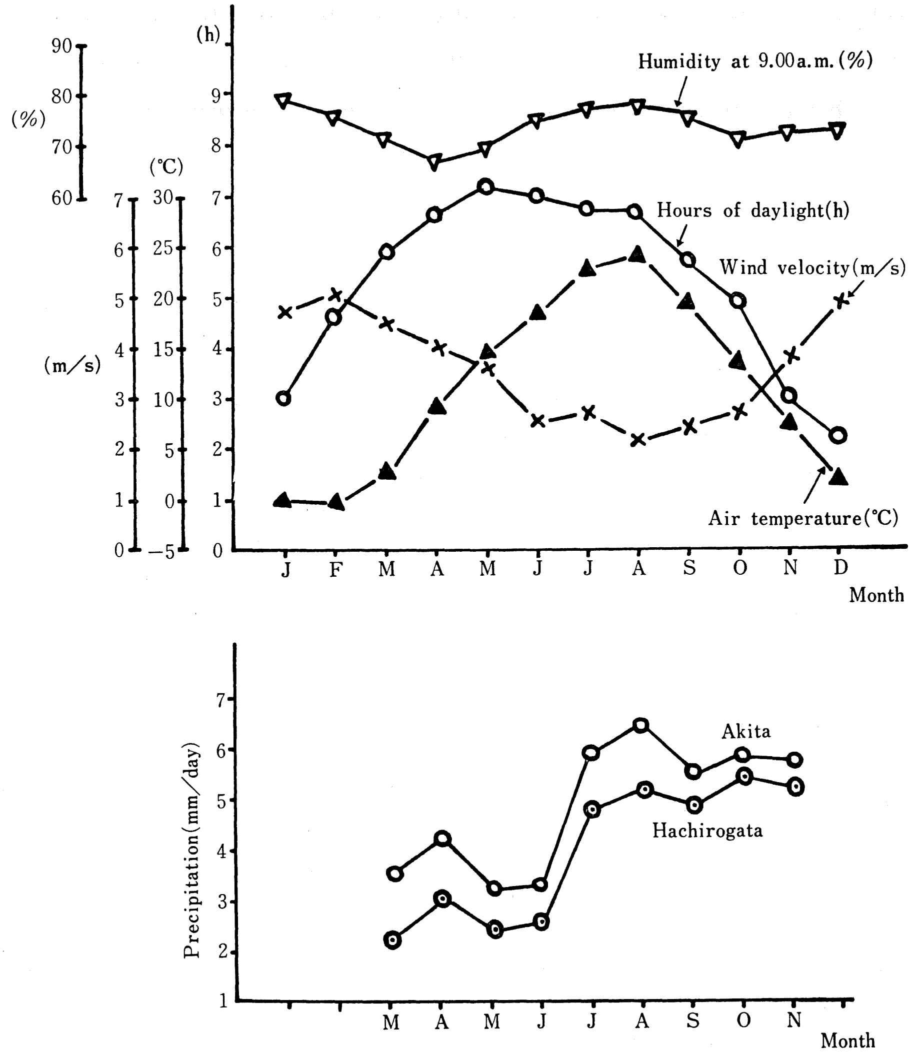


Fig. 1. Seasonal changes of meteorological factors (Mean value from 1966 to 1974).

the seasonal changes of meteorological factors.

a) Average precipitation is relatively low (2.6 mm/day) for the period from March to June, and high (5 mm/day) for the period from July to November. Amount of precipitation in the central polder is less as compared with Akita City.

b) Air temperature is highest in August, and from January to February it is below the freezing point.

c) Wind velocity in summer is comparatively weak, monthly mean wind velocity during the period from June to October being 2.5 m/sec.

Since the evaporation rate from the 20 cm pan (E_P) is related to solar radiation (R_S) as shown in Fig. 2 (Akita), we can consider E_P/r (r ; amount of precipitation) as the approximate climatic index of the drying of the ground. Therefore, it is clear from Fig. 3 that drying of the ground is progressed rapidly in Hachirogata Central Polder in May and June.

2. Growth of *Phragmites communis* in the marshy and heavy clay soil ground

1) Above-ground plant growth

a) Seasonal changes of plant height and leaf area

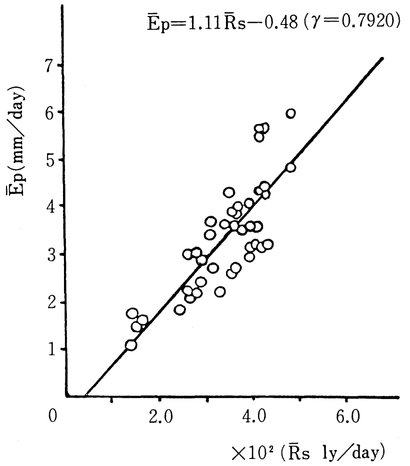


Fig. 2. The relation between solar radiation (R_S) and the evaporation from the 20 cm pan (E_P) —AKITA— (Values from April to November). [bar(—) : Average value]

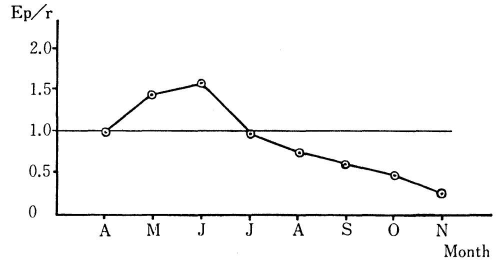


Fig. 3. Monthly change of the ratio of amount of evaporation in Hachirogata Polder Reclamation (E_P/r : Mean value from 1967 to 1973, r : Precipitation, E_P : Evaporation from the 20 cm pan).

Plant height of P. *communis* at point (a) in G_{14} station increases rapidly from late April and mean plant height exceeds 3 meters by late June. Then it increases only slightly until the time of heading in late August. Rapid growth in leaf area of P. *communis* was observed from the middle May to late August. The leaf area index (LAI) was more than 1 from the middle of May (Fig. 4).

b) The regeneration of P. *communis* after burning

Productive structure diagrams of P. *communis* at unburned point (a) and at burned point (b) (the fire on June 20, 1977) in G_{14} station in the middle of October are shown as Fig. 5. The following are clear from Fig. 5 in comparing burned point (b) with unburned point (a). 1) Plant height at point (b) is lower and production of leaves or shoots is smaller. 2) Both gradients of the vertical distribution of shoots are nealy equal. 3) The number of flowering stems at point (b) is remarkably small. 4) Density is nearly equal at both points.

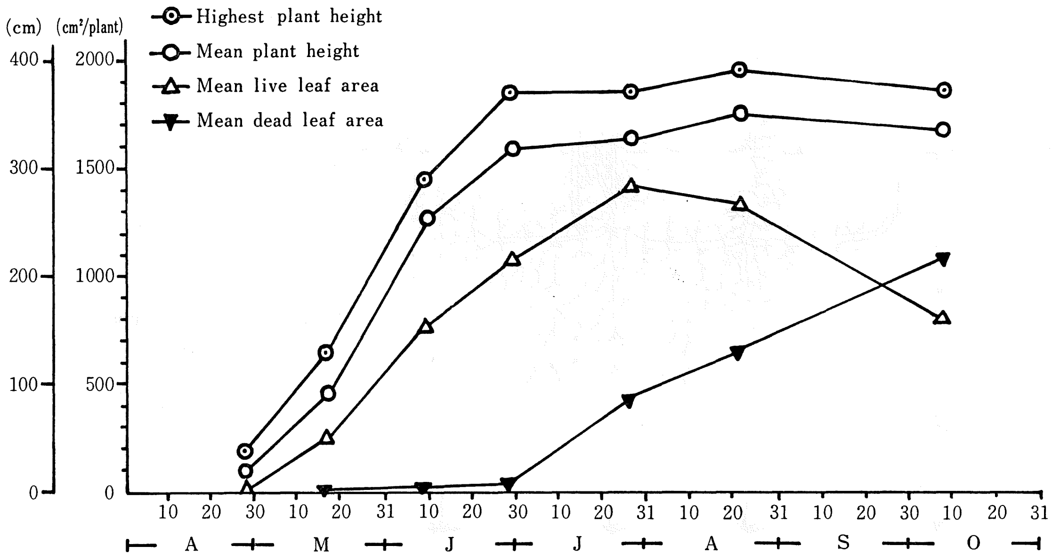


Fig. 4. Seasonal changes of plant height and leaf area of *Phragmites communis* Trin. (G_{14} station, 1975).

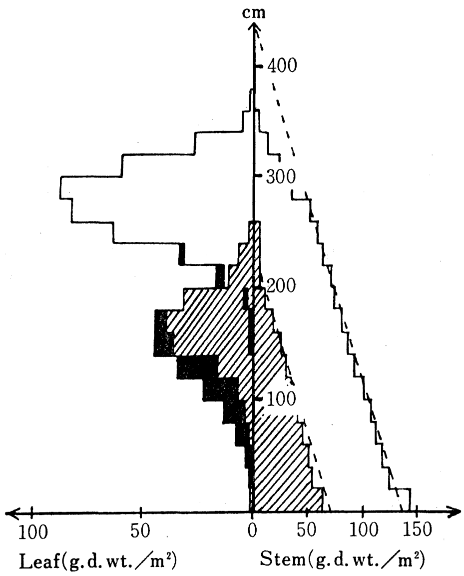


Fig. 5. Productive structure diagram of *Phragmites communis* Trin. (October, 1977). Open portion : P. *communis* at unburned point a. Density : 46 number/m^2, LAI of live leaves (dead leaves) : 4.9 (0.2), Numbers of flowering stem : 16. Shadowed portion : P. *communis* at burned point b. Density : 45 number/m^2, LAI of live leaves (dead leaves) : 2.7 (0.8), Numbers of flowering stem : 2. Black portion : Dead leaves.

2) The growth of under-ground parts of plant

In late summer, a bud near the base of the previous year's vertical rhizome develops into a horizontal rhizome growing in a similar direction to its predecessor. After extending about 1 m, the rhizome apex turns upwards, and remains dormant near the surface until the spring. Then it grows into an aerial shoot and flowers. Normally, the rhizomes of P. *communis* multiply, repeating this cycle[5]. Therefore, we can know the age of horizontal rhizome and the growth of rhizome (Fig. 6) etc., by tracing inversely this cycle. The following are clear from Table 1 and Fig. 6. 1) Horizontal rhizomes live for 13 years. 2) Annual growth of the current horizontal rhizomes is 60. 71～149.9 cm and elongation of new roots on rhizomes is small, compared with that of old roots.

3. Changes in soil water caused by evapotranspiration of P. *communis*

Table 1. The age of horizontal rhizome (October, 1977).

Sample number	Length of new horizontal rhizome (cm)	Age (year)
Sample 1	149.90	6
Sample 2	60.71	3
Sample 3	69.20	13

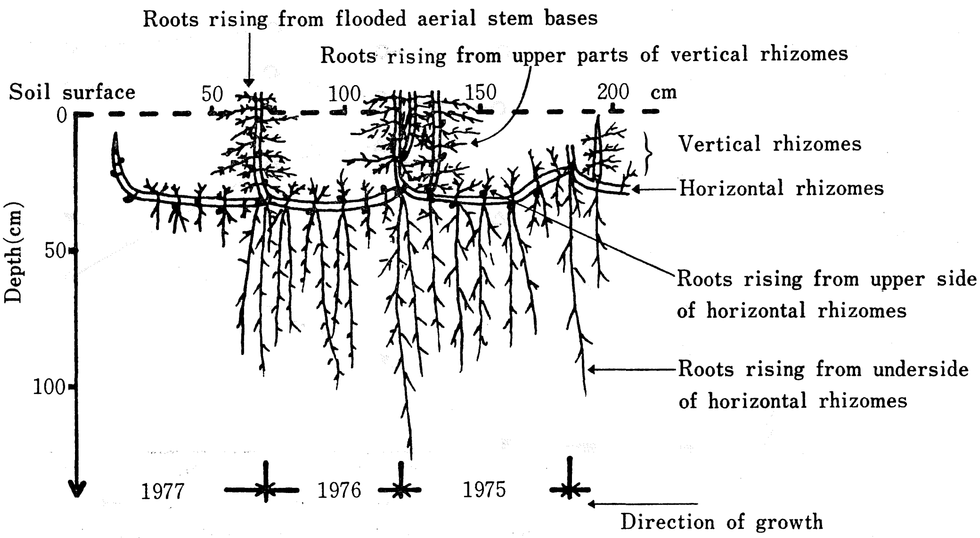


Fig. 6. Growth diagram of rhizome of *Phragmites communis* Trin.

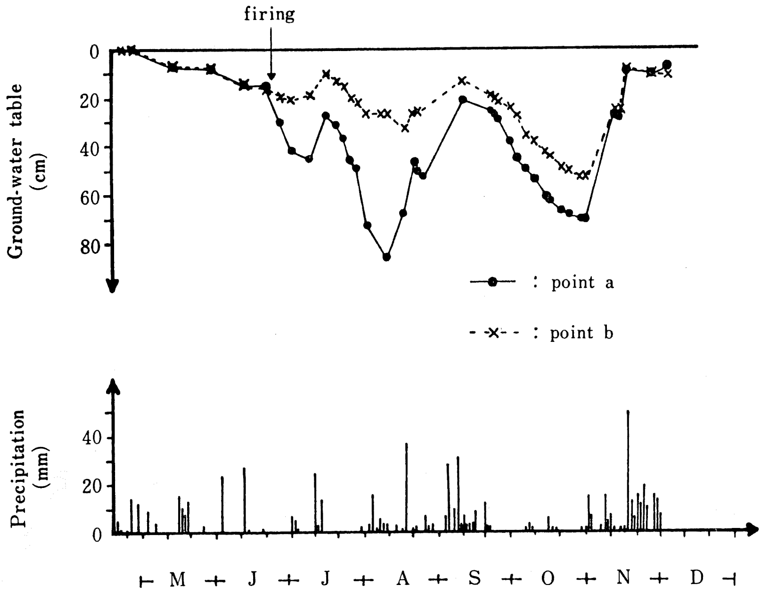


Fig. 7. Seasonal variations in the ground—water table in dense stands (G_{14} station, 1977). Point a : Unburned point, Point b : Burned point.

1) Seasonal changes in the ground-water table

Fig. 7 shows the seasonal change in the ground-water table in an area of dense stands of P. *communis.* Changes in the ground-water table in marshy and heavy clay soil grounds are closely related to the leaf area of P. *communis* and to rainfall[6]. As the soil surface is covered annually with dead leaves and stems of P. *communis* from November to March, very little evaporation from the soil surface can be expected during this period. Moreover, dense stands of P. *communis* are flooded at least for the winter season because of much rainfall and snow accumulation. The soil surface in April dries comparatively easily, because E_P/r becomes nearly 1 (Fig. 3) ; however, as the plant height and the LAI of P. *communis* are still very small, the level of ground-water table scarcely changes. The soil surface in May and June dries fastest in all the months of the year, because E_P/r reaches about 1.5. Moreover, as the leaf area of P. *communis* increases rapidly and the LAI increases in size to more that 1 from the middle of May, the ground-water table gradually lowers. Therefore, as there is comparatively little rainfall during this months, it is considered that the excess soil water accumulated in the soil during the winter season is eliminated mainly through the evapotranspiration of P. *communis.* During the rainy season in July, however, the ground-water table rises because the amount of rainfall is large. As the growth of P. *communis* becomes most vigorous with the ending of rainy season, the ground-water table falls remarkably due to evapotranspiration of P. *communis.* In October, the dead leaves of P. *communis* increase in quantity, air temperature falls, and the amount of solar radiation decreases. Therefore, the transpiration of P. *communis* is reduced and the ground-water table does not fall as much as during the height of the growing season.

On the other hand, in the case when above-ground parts of P. *communis* are burned down because of burning when they do not grow enough (point b, June 20 firing), changes of ground-water table are as follows. As soon as above-ground parts of P. *communis* are burned to ashes, transpiration falls to almost zero. Therefore, the ground-water table scarcely changes. But after a month (July 20), as mean plant height reaches 120 cm, the density of shoots reaches 45 per m^2, and the number of P.

communis leaves is 2～6 leaves per shoot, the ground-water table lowers gradually through the transpiration of P. *communis*. In the middle of October, the ground-water table falls even more, because mean plant height and LAI of P. *communis* increase to 199 cm and 3.5 respectively. However, we can see from this that burning during the growth of P. *communis* is disadvantageous to the drying of the marshy and heavy clay soil ground, because the ground-water table of the unburned point (point a) always falls more than that of the burned point (point b).

2) Changes in soil water

Diurnal variation of the soil moisture tension at various depths in dense stands of P. *communis* during a period of clear weather (1977. 8. 23-25) is shown in Fig. 8. The soil moisture tension at 5～30 cm in depth indicates negative pressure and rises during the day (6 : 00～18 : 00). Moreover, soil moisture tension increases and rises as drying progresses. The soil moisture tension at 50 cm and 70 cm in depth indicates positive pressure and decreases gradually. It is considered that these fluctuations

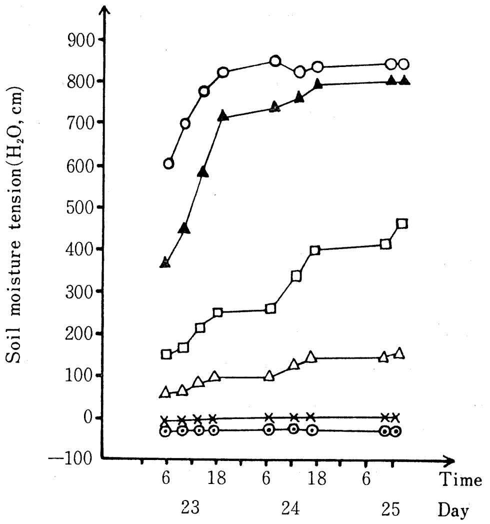


Fig. 8. Day to day variation of the soil moisture tension(G_{14} station ; point a, dense stands, August, 1977). -○- : Depth 5 cm, -▲- : Depth 10 cm, -□- : Depth 20 cm, -△- : Depth 30 cm, -×- : Depth 50 cm, -◉- : Depth 70 cm.

are directly related to the depth distribution of rhizomes and roots which absorb water at each depth. In short, it is considered that when the transpiration of P. *communis* becomes vigorous during the day, the replenishment rate of ground water to the root zone is smaller than the transpiration rate ; as the result, negative pressure increases with the progress of drying of the upper soil layer. The characteristics of soil moisture distribution in dense stands of P. *communis* becomes clear when compared with that in bare ground (Fig. 9). During continuous

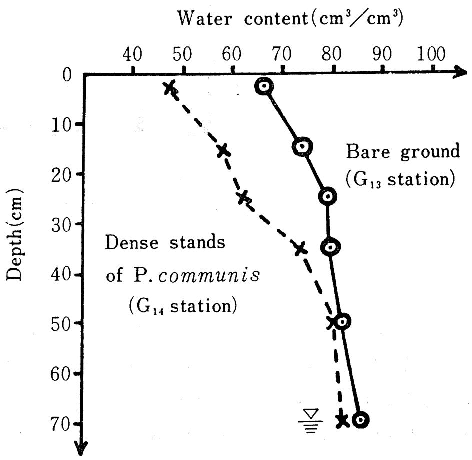
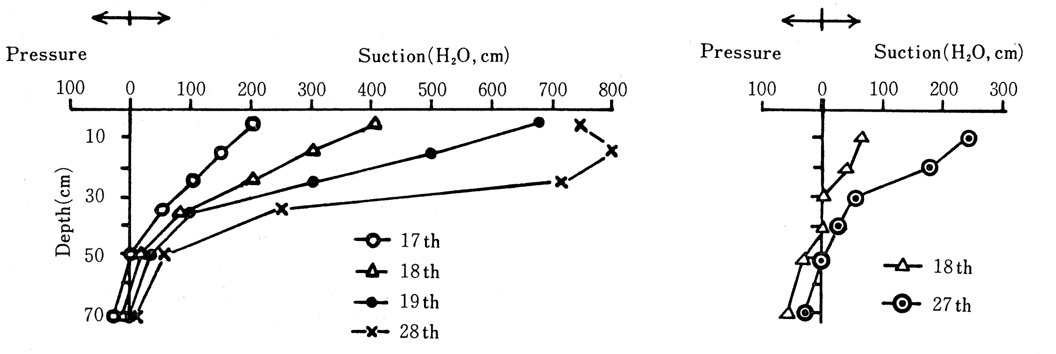


Fig. 9. Distribution of soil moisture content in soil profile during continuous drought conditions (October 21, 1977). ▽ : Ground-water level.

drought conditions, the soil water in bare ground is much greater than that in dense P. *communis* stands. Furthermore, in bare ground, the soil moisture gradient near the soil surface is greater than that of the deeper layers. In dense stands, however, the soil moisture gradient at the deeper layers is greater than that near the soil surface. It is considered that these differences in soil water and soil moisture profile occur because in bare ground, there is a sink of evaporation at the soil surface, while in dense stands, there is a sink of transpiration of roots in each depth[7]. Moreover, changes of soil water tension in dense and in sparse stands of P. *communis* during a period of continuous drought are shown in Fig. 10. As is clear from this figure, evapotranspiration in sparse stands is very small



Dense stands(G_{14} station, point a) Sparse stands(G_{13} station, point e)

Fig. 10. Variation in soil moisture suction during continuous drought conditions (July, 1973).

when compared with that in dense stands. Therefore, we can see that the shift of the field condition from dense stands to sparse stands of P. *communis* has direct effects upon the changes in soil water.

3) The evapotranspiration from dense stands of P. *communis*

The numbers of stomata per unit of leaf area of P. *communis* (35,500 and 56,100 per cm^2 on the upper and lower leaf surfaces respectively) are much greater than that of wheat (3,200 and 2,200 per cm^2)[8]. Accordingly, it follows that the transpiration of P. *communis* is very great under optimum conditions of growth, because stoma numbers are closely related to transpiration and because the LAI of P. *communis* is 7.6. The evapotranspiration values in dense stands obtained by the water balance method[9] in late July are shown in Table 2 together with the meteorological conditions during the observation periods. As is clear from Table 2, the mean daily evapotranspiration of P. *communis* varies with soil water conditions before the observation periods (for example, the soil water content of the surface layer at the start of measurement). That is, under wet (pF 2.0) or dry (pF 3.2) soil conditions, the evapotranspiration from the dense stands of P. *communis* was 9.8 and 3.9 mm/day respectively and the evapotranspiration ratio was 1.7 and 0.62 respectively. Water absorption by the plant from the soil is determined by the relation between plant water potential and soil water potential. Therefore, it follows that when soil water content decreases, the evapotranspiration of P. *communis* will decline because the soil water potential will gradually drop and water absorption by the roots of P. *communis* will become progressively more difficult[10].

Acknowledgements

The author is grateful to Emeritus Professor E.

Table 2. The evapotranspiration of P. *communis* (dense stands) and the meteorological conditions during the observation periods (G_{14} station, point a).

Item / Date	$\bar{E}_S$ (mm/day)	$\bar{E}_P$ (mm/day)	$\bar{E}_S/\bar{E}_P$	pF*	$\bar{h}$ (hours)	$\bar{P}$ (mm/day)	$\bar{t}$ (℃)	$\bar{u}$ (m/s)	R (%)
July 23-27, 1977	9.8	5.9	1.7	2.0	11.7	0	24.8	1.7	77.3
July 19-28, 1973	3.9	6.2	0.62	3.2	9.3	0	24.2	1.7	63.6

E_S : Evapotranspiration by the water balance method. E_P : Evaporation of the 20 cm pan. * : pF value at 5 cm depth at the start of measurement. h : Hours of daylight. P : Precipitation. t : Air temperature. u : Wind velocity. R : Relative humidity at 9.00 a.m.. [bar (—) : Average value]

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Summary

1. Plant height of P. *communis* increases rapidly from late April to late June with only a small further increase through heading in late August. The leaf area index increases to over 1 from the middle of May, and the net leaf of live leaves attains a maximum in late July.

2. The evapotranspiration from the dense stands of P. *communis* in late July was 9.8 and 3.9 mm/day under wet (pF 2.0) and dry (pF 3.2) surface layer soil conditions, respectively.

3. The fluctuations of the soil moisture tension at each depth in dense stands of P. *communis* occur through water absorption of the roots that are distributed at each depth.

4. The evapotranspiration in sparse stands of P. *communis*, is very small compared with that in dense stands.

5. The burning of above-ground parts on late June in dense stands slows the growth of P. *communis* and is thus disadvantageous to the drying of the marshy and heavy clay soil ground.

6. Horizontal rhizomes live for 13 years.

植生によるヘドロ地盤の乾燥に関する研究
—ヨシによる土中水分の変化—

神 尾 彪
(山形大学農学部農地造成学研究室)

摘 要

1. ヨシの草丈は4月下旬から6月下旬までにほぼ直線的に急増し，8月下旬の出穂期までに漸増する．ヨシのLAI(葉面積指数)は5月中旬に1を越え，7月下旬に最大値7.6をとる．

2. 7月下旬のヨシの蒸発散量は表層が wet の条件(pF 2.0)下で9.8 mm/day であった．

3. ヨシ純群落地における各深度の土壌水分張力の時間変化は各深度に分布する根による直接の吸水作用によって起る．

4. ヨシ群落が疎の場合（ヨシの密度が著しく減少している場合）には密の場合（密生したヨシ純群落）に比較して，ヘドロ地盤からの脱水効果はきわめて小さい．

5. 6月下旬の火入れによるヨシ地上部の焼失は植物体地上部の成長をおくらせ，ヘドロ地盤の乾燥にマイナスとなる．

6. 水平地下茎の寿命は最高13年まで認められた．