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SOIL WATER DISTRIBUTION IN MOUNTAINOUS AREA AND IRRIGATION PLANNING

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INTRODUCTION

The purpose of irrigation and drainage is to control the soil water content to the best condition for plant growth. In the humid region such as Japan, the amount of rainfall generally exceeds the potential evapo-transpiration. For example, the mean annual precipitation in Japan is about 1800 mm/year, and the mean annual evapo-transpiration is estimated as 600–800 mm/year. Therefore, the irrigation for upland field is usually considered to be unnecessary. But, the precipitation is nonuniform in time. A precipitation of over 200 mm sometimes occurs in one day. On the other hand, a drought period extending over 30 days sometimes occurs in summer. Therefore, irrigation is necessary to compensate for the irregular rainfall.

In a mountainous area, however, where orchard or tea garden has been reclaimed actively in recent years, the irrigation system has other purposes as well. It is important there to have an uniform soil water content not only in time but also in space. The soil water control becomes the critical condition for system planning or design in either case.

SOIL WATER REDISTRIBUTION IN A MOUNTAINOUS AREA

The soil water supplied from rainfall or irrigation is redistributed by drying force or evaporation and by gravity force. But they vary widely from one place to another in mountainous area.

The drying force can be evaluated by the solar energy recieved on the slope, which is effected by the angle between the soil surface and the solar beam. The solar radiation intensity is represented at each surface as follows,

$$I = I_0 \cdot \cos\delta \quad \cdots\cdots (1)$$

where I and I_0 are the radiation intensity on the inclined soil surface and on the perpendicular plane against the solar beam respectively, δ, the angle between both

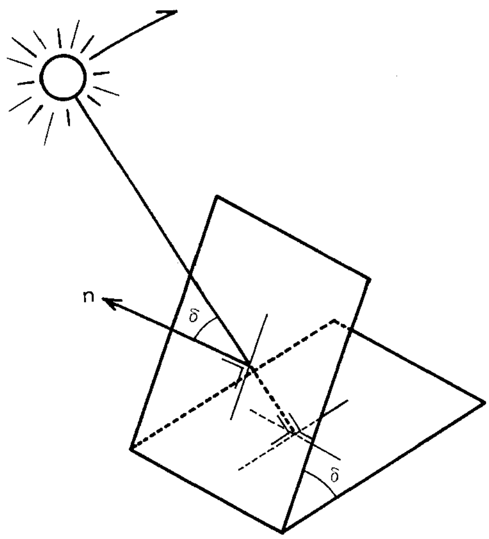

Fig. 1 Illustration of the solar radiation intensity on the slope plane

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planes (see Fig. 1). I_0 and δ at each point are chainging as the time elapses. Integrating Eq. (1) with respect to time for each point, we can obtain the accumulated energy distribution.[1]

The gravity force, which is the driving force of the lateral flow in soil and of the surface runoff, can be evaluated as proportional to the slope or gradient of the land. Zaslavsky[2] and Zaslavsky et al.[3] made the observation that infiltration of water is not necessarily directed straight down. Rather it has a horizontal component which is at least approximately proportional to the soil slope, ∇z, z being the soil surface elevation. As the conservation equation is applied to the horizontal flow component, the effect on the water redistribution can be estimated by the divergence of the land gradient (assuming other parameters independent of the soil surface coordinates).

$$\text{div}\ (\text{grad} z) = \nabla^2 Z \quad \cdots\cdots (2)$$

where z is the ground elevation.

Thus the redistribution of infiltrated rain or irrigation water should correlate well with the two factors mentioned, namely the radiation intensity and the Laplacian of the elevation.

ACTUAL SOIL WATER DISTRIBUTION

The soil water contents have been measured at 24 points at the experimental field in a certain mountainous area, where a national reclamation and irrigation project has been undertaken.

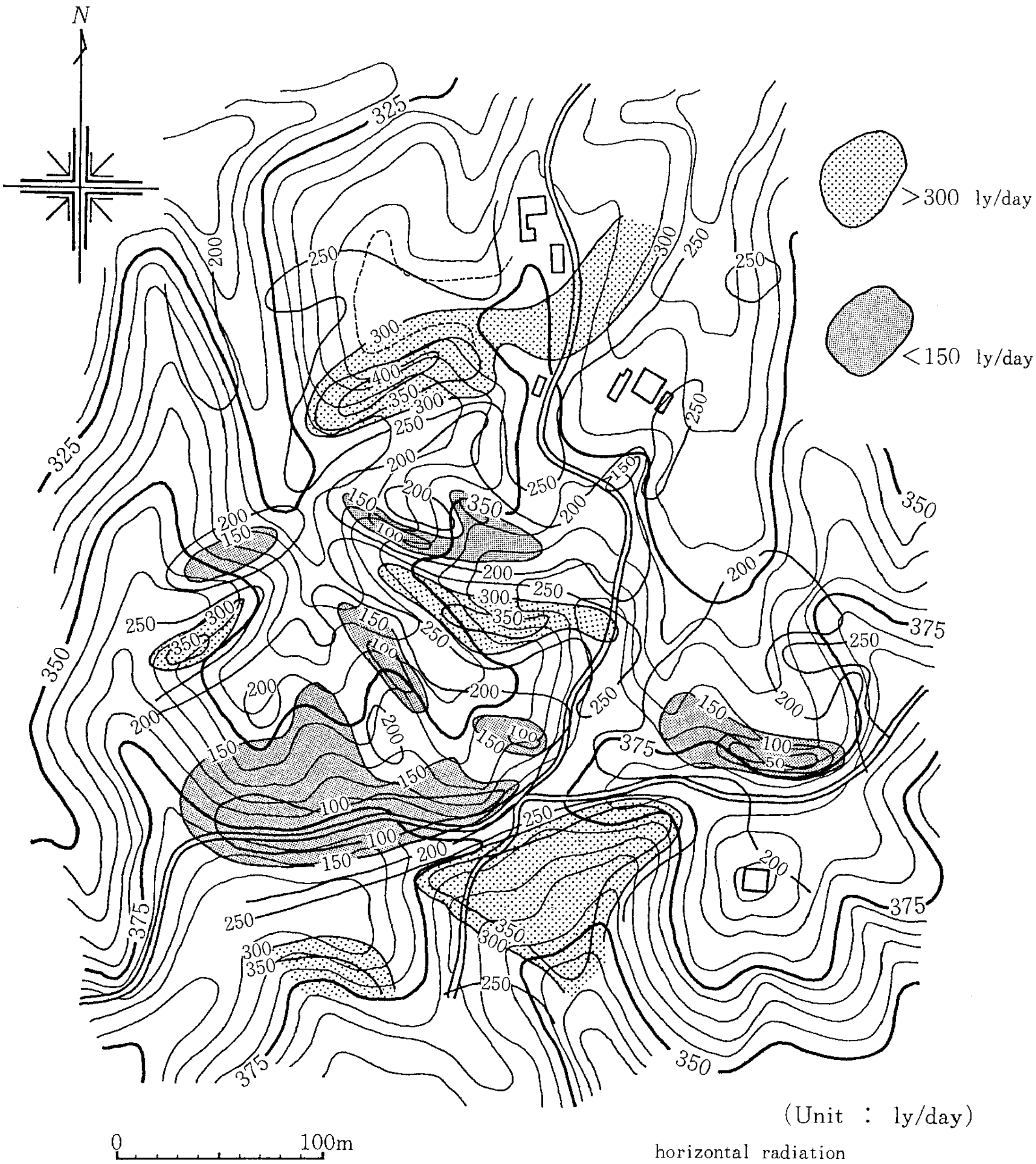
The solar energy distribution is calculated from the horizontal observed radiation at one point in this area, applying the above mentioned method. The solar energy distribution at Nov. 10, 1978 is presented in Fig.2. Its distribution is as complicated as the mountainous topography. At the same day, the pan evaporation was also measured as the index of the potential evaporation at each point where the soil water contents were measured. The correlation between the pan evaporation and the estimated solar energy distribution by the calculation at each point is presented in Fig.3. They correspond very well to each other.[4]

The divergence of the land gradient is approximated by a four points method for 19×16 grids represented as in Fig. 4. Interpolating linearly from this result, the zero-divergence line is drawn. The area is divided into two parts. One part is a divergent or convex area, where $\nabla^2 z<0$, and the other part is a convergent or concave area, where $\nabla^2 z>0$. $\nabla^2 z$ is approximated at each node as follows,

$$(\nabla^2 z)_0 = (z_1+z_2+z_3+z_4-4z_0)/4 \quad \cdots\cdots (3)$$

See Fig.5.

The measured soil water contents are plotted for the different solar energies. At the same time, each point is distinguished according to whether it belongs to the divergent area or the convergent area. It is represented in Fig.6. From this figure, we can draw a very interesting conclusion. There is at least a qualitative tendency of soil water change according to the position whether it is in a convergent (concave) or divergent (convex) area. The points near the zero-divergence line form a more



(Unit : ly/day)

horizontal radiation

total	294.6 ly/day
direct	234.7 ly/day
scattering	59.9 ly/day

Fig. 2 Solar energy distribution (Nov. 10, 1978)

or less univalent function of the solar energy.

The Laplacian of the land elevation also represents the curvature of the land surface as in Fig.7. In the divergent area where the curvature is negative, the soil generally tends to be carried away, on the contrary the soil from there tends to be accumulated in the convergent area. It has been proved that the water retention of

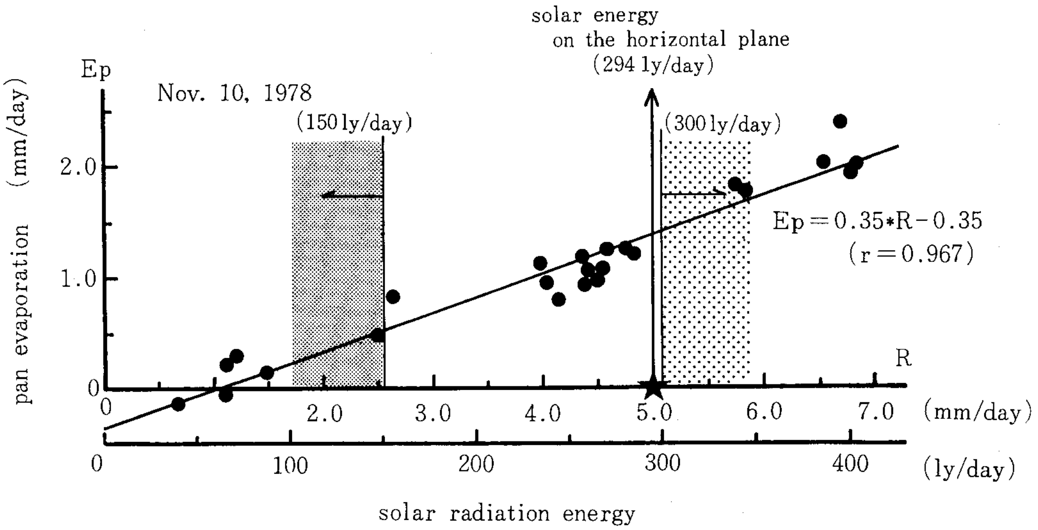


Fig. 3 The relation between pan evaporation and solar energy (T,Mitsuno et, al, 1979)

the soil is poor in the top, but it is strong in the valley.[5] It is considered that each area having such a different character also corresponds to the divergent and the convergent area respectively. As the Laplacian becomes a good index not only for the water accumulation but also for the soil water retention, the actual soil water distribution strongly depends upon it.

The data of this experiment make not intended originaly for this interpretation. Therefore they can not provide a quantitative correlation with the concavity. However the results comply with results found by Zaslavsky through calculation and field experimentation.[3] After redistribution the available rain water in the soil can vary as widely as 1 : 5.

THE ROLE OF IRRIGATION, DRAINAGE AND SOIL CONSERVATION IN MOUNTAINOUS AREA

One of the important purposes of the irrigation and drainage is to adjust artificially the soil water content for the best condition to plant growth. This artificial adjustment must counteract the natural tendency for redistribution as it was expressed in the previous section. The irrigation is necessary for the divergent and large evapotranspiration area and the drainage is necessary for the convergent and low evapotranspiration area. Their combination is required for the land development in mountainous district.

Then, as the first step of land classification for land reclamation planning and irrigation planning, it is recomended to map the divergent and the convergent areas according to their concavity, and to plot the solar energy distribution. Both are obtained from the analysis of topographic data. It is possible that a curvature map

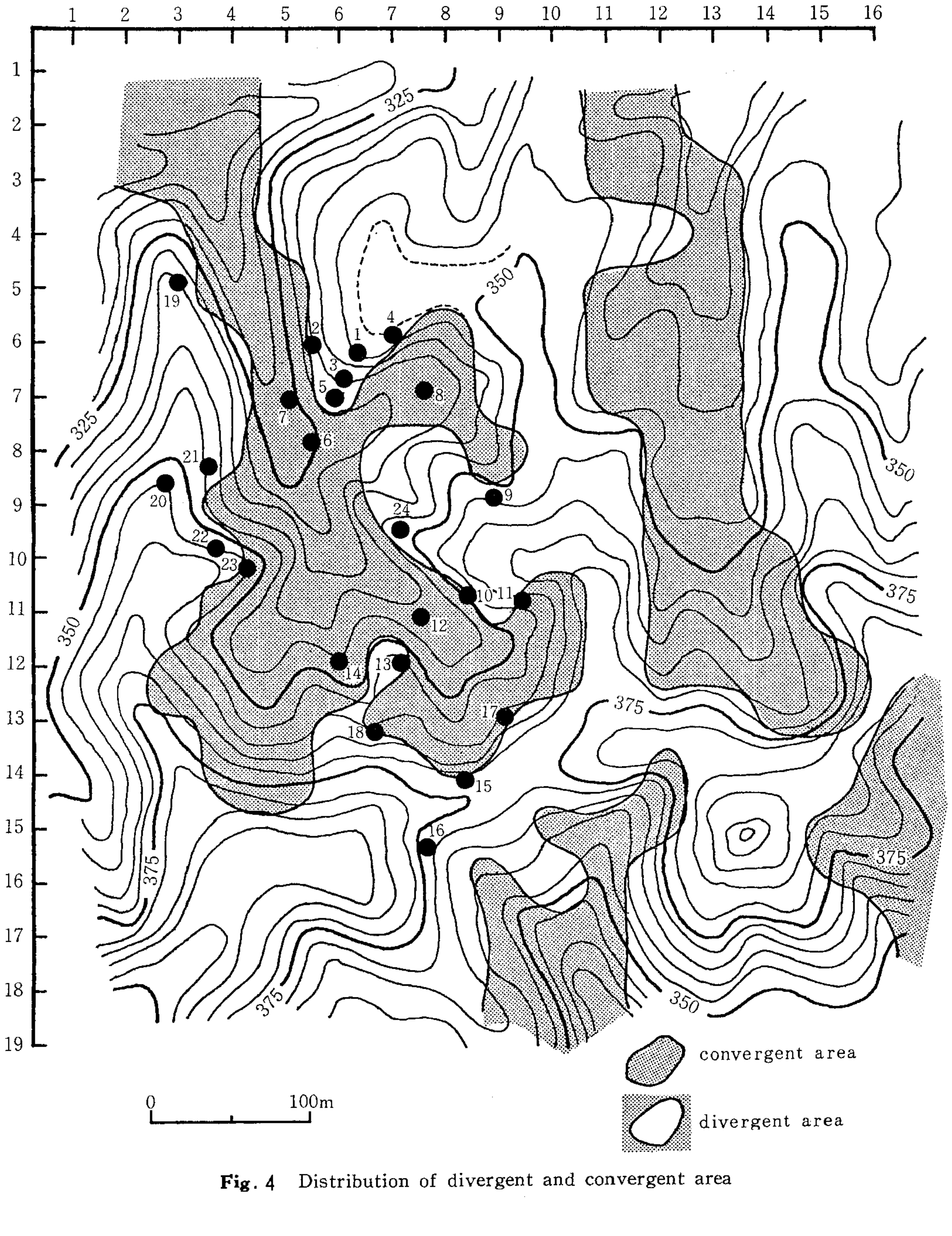


Fig. 4 Distribution of divergent and convergent area

(a divergence of the land gradient map) superimposed on a map of the solar radiation will serve as the basis for planning and design.

In concave areas, water accumulation occurs, and there more intensive errosion may occur. Thus it is quite possible that the same mapping system will also serve as a basis for some conservation measures.

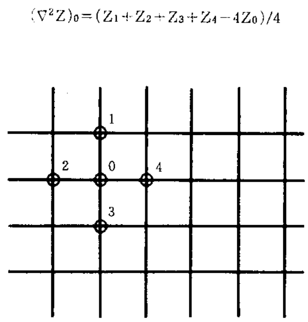


Fig. 5 The approximation of the Laplacian of the ground level

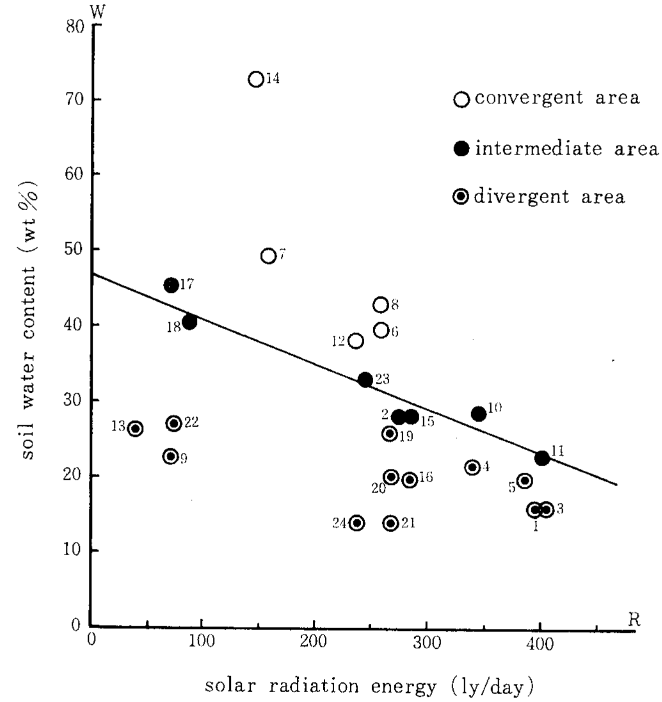


Fig. 6 Relation between the measured soil water content and solar radiation energy

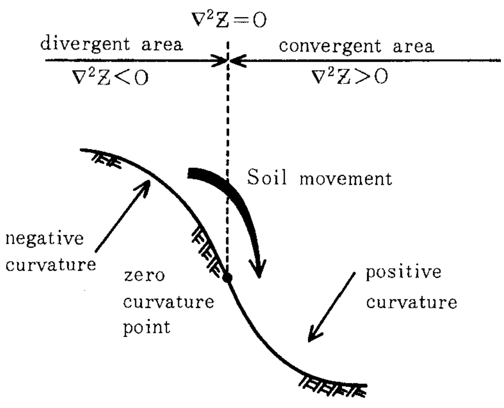


Fig. 7 Illustration of the divergent area and convergent area

IRRIGATION UNIFORMITY

A very interesting study has been carried out on persimmon yield and its dependence on soil moisture. An analysis was made of the total production data for last ten years in this district.[6] Persimmon is the main fruit for the agricultural production there. The yield has been found to be affected remarkably either in quantity or in quality by the amount of the annual effective rainfall. Namely, the persimmon yield is very sensitive to the soil moisture content. The soil moisture varies remarkably not only in time but also in space due to redistribution. Therefore, the yield might vary widely in space.

The divergence or convergence of moisture occurs notably following rain. It also follows irrigation in a similar way. The uniformity of irrigation is an important parameter that affect the yield. The effect of soil moisture variation to the yield can be evaluated as follows,[7]

$$\overline{Y} = Y(\overline{Q}) + (d^2Y/dQ^2)\cdot\sigma^2{}_Q$$

where $\overline{Y}$ is the average yield, $Y(\overline{Q})$ is the yield at the average water application $\overline{Q}$,d^2Y/dQ^2 is the yield response to water and $\sigma^2{}_Q$ is the variance of the moisture in the field.

Generally d^2Y/dQ^2 is negative, then the larger the moisture variance becomes, the less the yield becomes under the same amount of water. In mountainous area, the variance due to the water redistribution in soil is probably very large. From the viewpoint of water economy, the water redistribution becomes an major problem.

Large efforts have been devoted to improve the water sprinkling pattern with Cristiansen's coefficient on the inclined field. The soil water variance can not be improved only by the water sprinkling system. It is necessary to offset the natural tendency of the water redistribution due to the lateral flow in the soil. This tendency is similar for both the rainfall and irrigation. In principle one can do one of several things among them :

a. choose only convenient areas of the proper limits on concavity.
b. specify the necessary soil surface grading.
c. delineate small lots of uniform concavity and give each a different treatment.
d. invent an irrigation technique that will be less sensitive to lateral redistribution.

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REFERENCES

1) T. Miura, T. Mitsuno, T. Maruyama and A. Yomota : Calculation methods of the distribution of the amount of insolation in mountainous area — Studies on the mechanism of the thermal environment formation in mountainous area (I) —, Trans. of JSIDRE, No.88, pp.1- 7, 1980
2) D. Zaslavsky : Some aspects of watershed hydrology, Special Report to the U. S. Dept. of Agriculture, Agric. Res. Serv., ARS., 1970
3) D. Zaslavsky and G. Sinai : Surface Hydrology, Note 1017, Instituut voor Cultuurtechnicken Waterhuishouding Wageningen, 1977
4) T. Miura, T. Mitsuno and T. Maruyama : Calculation methods of the distribution of the amount of insolation in mountainous area and its applications, Preliminary Report of the Convention of Japanese Soc. of Agric. Met., p.43, 1979
5) T. Mitsuno : Distribution of heat energy and water, and soil physical conditions in a new reclaimed inclined field, Soil Physical Conditions and Plant Growth, Japan, No.37, pp.22-28, 1978
6) N. Fusayama : Practical verification of irrigation necessity for persimmon, Green Field, No.213, pp.46 51, No.215, pp.51-70, 1976
7) D. Zaslavsky and N. Buras : Crop yield response to non-uniform application of irrigation water, Trans. of ASAE, pp.196 200, 1967

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