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Mini Review

Insolation of Slopes in Agriculture and Ecology

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Abstract

Photosynthesis and heat are important for crop yields and forest productivity. Therefore, even small changes in insolation can lead to significant changes in yields. Since slope insolation depends on perpendicularity of sunlight falling on land surface, it also depends on slope steepness and exposure, the role of which is often underestimated and rarely measured. We demonstrate how to take these factors into account and the implications of this for crop yields and forest productivity.

Keywords: Crop yields; forest productivity; slope insolation; light and thermal regime

Introduction

Along with climatic factors, light and thermal regime of slopes have a significant impact on agricultural crop yields [1,2] and forest productivity [3-5]. Environmental factors used in predictive modeling of agricultural crops, soils, and forests are described in the review [6]. To account for the distribution of solar radiation across slopes, slope insolation F(a,b) is particularly important. It describes perpendicularity of the incidence of solar rays on the land surface. Here, a and b are angles describing the position of the Sun: a is inclination above the horizon, and b is azimuth measured from the north clockwise. Insolation depends on both slope steepness and exposure. Of practical importance is the effective position of the Sun, which can be found as follows. In mid-latitudes, the correlation coefficient between such a landscape characteristic as grass abundance and F(a,b) depends very weakly on the declination angle a in the practically important range of a = 25°-45°. Therefore, here this angle can be taken as fixed, a_0 = 35°. The dependence of $F(a_0,b)$ on azimuth b is significantly stronger. The value of the effective azimuth b_0 can be found by plotting a curve of the correlation coefficient r between the vegetation property being studied and $F(a_0,b)$ as a function of azimuth b. The point of maximum r on this curve yields the effective azimuth b_0, at which the relationship between given vegetation property and $F(a_0,b)$ is strongest. An example is shown in the figure.

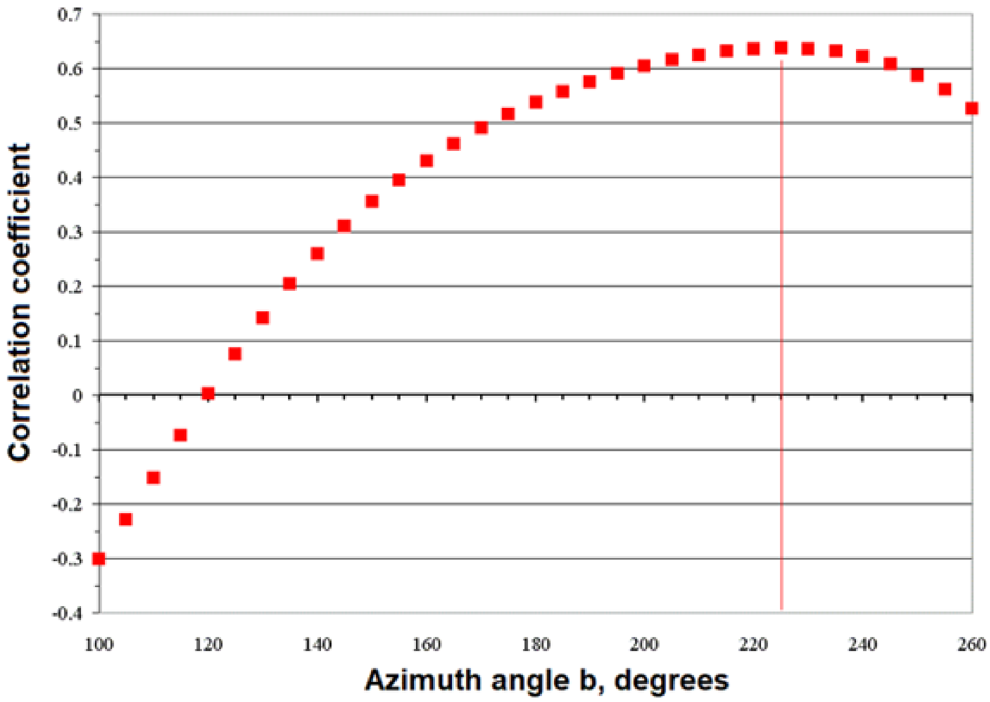

Figure 1: Finding the effective azimuth b_0 for winter wheat yield. Correlation is between crop yield and insolation $F(a_0,b)$ values. The vertical line shows $b_0 = 225°$ (southwest slopes). Data from [2].

In the Northern Hemisphere, b_0 typically corresponds to southwest-facing slopes ($b_0 = 210°-250°$), which warm up better due to the lag in heating the root zone of the soil compared to instantaneous solar radiation. Although the angles in $F(a_0,b_0)$ are fixed, this variable still depends on slope steepness and aspect, varying from one observation point to another. Slope insolation is usually expressed as a percentage, assuming 100% for the perpendicular incidence of solar rays [7]. However, it can also be expressed in energy units (W/m^2), taking into account that on a clear day, the solar radiation power per unit area perpendicular to the rays is $\tau = 760\ W/m^2$ in mid-latitudes. Then, insolation in energy units F_{EN} is $F_{EN}(a,b) = 0.01\tau F(a,b)\ W/m^2$. Although on cloudy days diffuse radiation predominates, this only reduces the contrast of the F map, having little effect on the pattern of the insolation map, but somewhat reducing the relationship between the studied soil property and F [8]. Other quantities describing solar energy are also known. For example, integrating the sun's motion over a given time yields the solar radiation dose PRR (Potential Relative Radiation) in J/m^2 [8], independent of the angles a and b.

However, PRR cannot be used to determine the effective azimuth and inclination, which is why PRR emphasizes the slopes that receive the most sunlight (southern slopes in the Northern Hemisphere) rather than the warmest slopes (southwestern slopes), which are more closely associated with vegetation (Figure). Therefore, using $F(a_0,b_0)$ in predictive modeling is more convenient than PRR. For example, the average annual yield of winter wheat in the Oka River basin (Russia) was highest for $F(a_0=35°, b_0=235°)$, and this insolation for yield was the most significant environmental factor, with its increase by 25 W/m^2 (this is only 5% of the average) leading to an increase in yield by 1.5-2 times [9]. On a global scale, insolation significantly influences the distribution of climate across the Earth, as the incidence of sunlight on the Earth's surface becomes less perpendicular as one approach the poles, heating the land surface less; stronger attenuation of solar irradiation by air at small inclinations is added to this.

Sometimes, for simplicity, instead of slope insolation, the function of aspect A_0 equal to 1 for southwestern slopes is used, $-\sin(A_0+45°)$ [4,10], which a priori assumes southwestern slopes to be the warmest. However, this is not always real for many reasons, such as the influence of prevailing winds. For biotic soil properties, such as soil organic carbon content, slope insolation is often among the leading environmental factors, since it is associated with photosynthesis and thermal regime of soils, while for abiotic soil properties, such as heavy metal concentrations, other environmental factors are more important that characterize water flow accumulation, terrain dissection, or land forms [11].

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Conflict of Interest

No Conflict of Interest.

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