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Radiation interception and use by maize/peanut intercrop canopy

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Abstract

The efficient use of solar radiation is one of the major criteria for obtaining a yield advantage through intercropping. Although various combinations of crops have been reported for intercropping systems, the maize/peanut association has yet to be analysed. This report presents the radiation-use efficiency (ε) results of a maize/peanut intercrop study. The experiment constituted three treatments: sole crops of maize and peanut, and a maize/peanut intercrop. The canopy light extinction coefficient (k) of peanut was reduced while intercropped with maize. The mean ε of intercropped peanut (2.13 g(DW) MJ^{-1}) was 79% higher than that of peanut stands alone. The ε of combined intercropped stands (3.03 g(DW) MJ^{-1}) was more than two-fold that of sole peanut, but slightly lower than that of maize stands alone (3.27 g(DW) MJ^{-1}). The harvest index (HI) of intercropped peanut was about 13% lower than that of peanut grown alone, but produced 46% of the pods of the latter (299 g m^{-2}), the parameter that represents the true output of this intercropping system. These results suggest that a maize/peanut intercropping would help to increase production through the efficient utilisation of solar energy. A simple model was developed to isolate the daily radiation interception of each of the canopies of the intercrop partners in separate strata, taking into account the alteration of the k of the understorey. The model may also be applicable in agroforestry systems.

Keywords: Light extinction coefficient; Light partitioning; Spatial transmission; Subordinate canopy

1. Introduction

In the modernisation of crop production, most methods used by growers to achieve better yields have largely been explored. Most of these methods involve increasing the efficiency of the utilisation of natural resources such as the water and nutrients in the soil, land area, solar radiation, and atmospheric CO_2. Many of these natural resources are becoming more limited, which constitutes a threat. However, the intensity of solar radiation will remain relatively constant, and represents a resource that could be used more efficiently for crop production. The abundant radiation available over the tropics and subtopics presents a great opportunity to increase its use for better crop production.

The amount of cultivable land is gradually decreasing, mainly because of rapid urbanisation and industrialisation due to the global population explosion. The limited land areas are facing pressure to meet basic demands, especially for food, fibre, and oil. Most growers own very small plots of land, especially in the developing countries of Asia and Africa. These growers

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require not only increased production, but also the ability to grow multiple crops in small areas. Intercropping is one sustainable idea that can greatly increase the use of solar radiation. The additional solar energy used by the intercrop canopy leads to improved crop production, and thus greater economic yield. Over the past three decades, there has been much study on the uses of radiation in intercropping and alley cropping systems for a wide range of crop combinations (Ofori and Stern, 1987; Corlett et al., 1992; Keating and Carberry, 1993; Black and Ong, 2000, and references therein). However, the association of maize and peanut had not yet been analysed.

In intercropping systems, the combination of partner crops depends mainly on the crop geometry, but also on the growth habit, life span, and management practices of the crops; climatic conditions; local food habits; growers' demands; and finally the benefits, whether in terms of crop yield, economics, stability, or sustainability (Connolly et al., 2001). In most cases, dominant and subordinate partners constitute the intercrop mixture. Generally, the former partner is highly dominant over the latter, and is a monocotyledonous cereal due to the erectophilous architectures and isobilateral leaf characteristics of these species. The erect canopy absorbs incidental radiation very effectively through both leaf surfaces, while allowing a sufficient amount of radiation to reach the subordinate crop. In contrast, the subordinate species is selected from those with planophile canopies, which trap the maximum amount of radiation transmitted from the dominant crop. The canopy geometries of the dominant and subordinate stands form different types of growing mixtures: two (or more) separate strata, separate below/mixed above or *vice versa*, or completely intermingled. In intercrops with separate strata, the dominant canopy grows independently of the subordinate species with almost no changes in its canopy architecture or radiation characteristics. In contrast, the canopy geometry of the subordinate species is likely influenced to a great extent by the shading offered by the dominant canopy, but information on the underlying concept is still lacking.

To compute their individual ε values of the species, it is essential to determine the proportions of radiation intercepted by the partners on a daily basis. Several models have been reported in this regard (Marshall and Willey, 1983; Rimmington, 1984, 1985; Wallace et al., 1991; Sinoquet and Bonhomme, 1992; Sinoquet et al., 2000). However, the application of those models is very complex, and a large number of input variables and complicated mathematics would be required. Moreover, such models for intercrops with separate strata would be verbose in practice. Most of the models are based on Beer's law, and interestingly, this law is perfectly appropriate for crop mixtures in which the canopies form separate vertical layers (McMurtrie and Wolf, 1983). The canopy's radiation extinction coefficient (k), the most critical element of Beer's law, defined as the average projection of leaves onto a horizontal surface, is a function of the area and form of the leaf, the leaf inclination, the zenith angle of the sun, and the leaf's azimuth. In the case of the subordinate species, the use of the same k for both sole crop and intercrop stands in model development is inappropriate, as the canopy architectures of the understoreys in each case would be different (Graf et al., 1990; Wallace et al., 1991; Keating and Carberry, 1993). Nonetheless, some models have been designed that do not use the k of the partner species involved (Rimmington, 1984, 1985). Moreover, partitioning of radiation based on the vertical difference leads to a large underestimation (Wallace et al., 1991; Wallace, 1997; Tsubo and Walker, 2002), as the interception of radiation is independent of the stand height. Therefore, the past models have inherent limitations and thus warrant either further development or simplification. An improved model should be simple with few input variables for easy, rapid, and accurate estimations.

The extinction coefficient computed from Beer's law may provide accurate estimates of radiation interception by a sole crop or by the dominant crop of a mixture, which receive uniform direct solar rays, but it would probably not provide accurate measures of k or thereby prediction of light interception for a subordinate canopy, which experiences mostly diffuse radiation (Montieth and Unsworth, 1990; Campbell and Norman, 1998). Therefore, the k of a subordinate stand depends not only on its own canopy architecture and its optical properties but may also depend on some of the architectural and radiation characteristics of the dominant canopy. A new approach that takes this concept into account is needed.

Based on the above facts, the present field study was conducted to analyse radiation interception for use in exploring the yield advantage of a maize/peanut intercrop canopy, and to propose a simple model for the canopies of the separate layers in order to isolate the proportion of radiation intercepted by each partner on a daily scale.

2. Analysis of measurements

Assuming that the canopy foliages are horizontally homogeneous, the amount of radiation intercepted (I)