Solar radiation utilization efficiency in cereal-legume intercropping systems: A review

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Received: 04-09-2016 Accepted: 15-11-2016

ABSTRACT
Growing two or more crops together with close proximity has the challenge of utilizing the available resources. Crop yields need to be increased by improving the use efficiency of resources such as water, nutrients and solar energy. Intercropping is often a means to better use of land and other resources. Success of cereal-legume intercropping will depend on extent of harnessing solar radiation by the canopy profile. Several field experiments conducted in southern Great Plains have indicated radiation use efficiency has a means to evaluate efficiency. In this paper, the growth and utilization of annual legumes as intercrops is reviewed with particular reference to resource use and their feasible with cereals.

Key words: Radiation use efficiency, Intercropping, Light interception, Cereal-legume.

The most common goal of intercropping is to produce a greater yield on a given piece of land by making efficient utilization of resources (i.e., soil, water, solar radiation, human and animal resources) that would otherwise not be utilized by a single crop. Intercropping can be defined as growing two or more crops in proximity to promote interaction between them. It is not a haphazard mixture of several crops but is often an orderly arrangement with different crops in separate rows (Anil et al., 1998). The canopy light environment in narrow-wide row planting patterns was improved and RUE was significantly increased with narrow and wider row combinations in maize (Tiedong Liu et al., 2012). Most important reasons to follow intercropping system are to utilize the growing season and markedly increase in productivity per unit land. Potential benefit is to stabilize the yield and income to the farmer over the seasons in view of the frequent failure of crops under rainfed system. The quantity of nitrate leaching is reduced due to intercropping as reported by Whitmore and Schroder (2007). The concept and management was different in irrigated and rainfed cropping systems. The inclusion of grain legumes in forage intercrops can provide a more sustainable source of N to cropping systems through biological N fixation (Crews and Peoples, 2004). For grain crops, harvesting dates are different in spite of same date of sowing, whereas forage based component crops are harvested at the same time and mixed together. Quality of forage mixture is the primary objective in addition to total biomass yield. When two or more crops are growing together, each must have adequate space to maximize cooperation and minimize competition between them. To accomplish this, four things need to be considered: spatial arrangement, plant density, maturity dates of the crops being grown, and plant architecture. Based on the above concepts, different types of intercropping systems practiced across the globe are: arrow intercropping, strip intercropping, mixed intercropping, relay, multistory and alley intercropping.

Concept of intercropping: Intercropping has a long history, and is employed in many regions. In tropical agriculture, tall and short crops are grown together to maximize production. To accomplish this, there is a need to consider spatial arrangement, plant density, maturity dates of the crops being grown and plant architecture. In arid regions, intercropping improves the conservation of water and efficiency of applied nutrients. In temperate countries, most of the cereals area is under forage production system. Throughout time and around the world, intercrops have been used to match better crop demands to available sunlight, water, nutrients and labour. The advantage of intercropping over sole cropping (growing a single crop in a field) is that competition for resources between species is less than that exists within the same species. It provides an efficient utilization of resources, reduces risk to the environment and costs of production. Very recently, there has been a rapidly growing interest in intercropping as a consequence of shrinking arable land resources.

Crop compatible issues: In most of the developing countries, cereals are grown mostly for grain purpose. The component crops selection and definite row planting is a challenge. In addition to management practices, physiological development and maturity of species can play significant role. There are many practical management problems include sowing, spraying herbicides, plant protection

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chemicals and mechanical harvesting. Several indices were used to evaluate performance and productivity of intercrops. It also depends on the purpose in which crop combinations were made (Lithourgidis et al., 2011).

**Radiation interception (RI):** During early stages of growth, enough LAI is needed to use most of solar radiation falling on the soil. Maximum use of solar radiation usually occurs at a certain LAI, the duration of which is usually relatively brief in short duration crops. Multiple cropping allows better use of energy. A sole crop of corn may use 75 per cent of light while corn intercropped with mungbean will intercept 95 per cent of the incident light. Intercropping system is one type of mixed cropping system common among tropical and sub-tropical countries. Over three decades researchers predicted the intercropping advantage in terms of yield and biomass gain over monocropping. The line quantum sensor is usually one meter in length and 12.7 nm in width. It is made from an array of stability silicon photo voltaic detectors placed at 2.38 cm apart. These detectors are placed in a water proof anodized aluminium case with acrylic diffuser and stainless hardware. The sensor output is connected to an integrating quantum meter along with a calibrated connector. Radiation interception measurements cane made with line quantum sensors between 1100 to 1400 h in unabsorbed light by taking a measurement above the canopy and below the canopy. The sensor is placed perpendicular to the row direction of crop horizontally at the ground level to get transmitted PAR (TPAR). The quantum sensor output is given in E S^{-1} m^{-2}. RI was calculated as

\[
RI = 1 - \frac{\text{Average PAR below canopy}}{\text{PAR above the canopy}}
\]

Total daily radiation was logged at an automated weather station and converted to PAR values by multiplying 0.48. The profile absorbed PAR place the sensor at definite crop height and TPAR is noted at respective heights. Diurnal IPAR can be measured by hourly readings from sunrise to sunset.

Several authors have evaluated in terms of PAR interception and utilization by the component crops. Intercrops in general, utilize the resources like soil moisture, light and nutrients compared to main crop. In dense planted cereal-legumes intercropping system, tall statured cereals may restrict the light available to beans. However, climbing nature of beans can explore more light (Tsubo and Walker, 2002). Several studies showed that significant influence of reduced light levels on growth and biomass yield of legume crops (Stirling et al., 1990). A sole crop of corn may use 75 per cent of light while corn intercropped with mungbean will intercept 95 per cent of the light (Mishra and Kler, 2000). It seems to be severe depending on species, age, length of shading period and environmental conditions (Buxton and Fales, 1993). Plant itself can acclimate to changes in light energy at the whole plant level changing the biomass partitioning among leaves, stem and roots (Evans and Pooter, 2001). Leaves are the most exposed plant organ to aerial conditions and it is well documented that the variation in light intensity can induce morphological and physiological modifications.

**Radiation use efficiency (RUE):** Radiation use efficiency was calculated as the ratio of chemical energy/dry matter increase per unit of radiant energy intercepted by plants. Reliable estimates of RUE are dependent on obtaining frequent and precise estimates of intercepted PAR or solar radiation, biomass, and the leaf area index (LAI) throughout the growing season. Lindquist et al. (2005) estimated RUE using the short-interval crop growth rate method, the cumulative biomass and absorbed PAR (APAR) methods. The crop growth rate determined between two consecutive harvests divided by the quantity of radiation intercepted during that period. Most common method of estimating RUE was utilizing the accumulated biomass and cumulative radiation interception. Always linear relationship exists with each other. Radiation interception varies from seedling emergence to crop harvest (Watiki et al., 1993b) and depends largely on the canopy leaf area. Further leaf area index (LAI), crop extinction coefficient (k) and carbon exchange rate (CER) are dependent on RUE. High LAI along with lower ‘k’ values contributed for higher RUE inspite of lower CER (Kiniry et al., 1999). Radiation use efficiency was calculated by several ways wherein biomass or gain yield considered in relation to light interception

\[
RUE = \frac{Y_{\text{biomass}}}{I_0 \times F}
\]

Where, \( Y_{\text{biomass}} \) was aboveground biomass (g m\(^{-2}\)) and \( I_0 \) was the flux density of the incident PAR above the crop canopy (MJ m\(^{-2}\)).

Another way of RUE determination by regressing biomass sampled periodically throughout the season against the cumulative intercepted PAR. The cumulative PAR will be accumulation of daily PAR in relation to biomass sampling. In a places where daily incoming terrestrial radiation was not recorded from weather station workout as per the procedure provided in FAO Irrigation and drainage paper 56 (Allen et al., 2000).

Under adequate supplies of both water and nutrients, yield can be described as the product of intercepted radiation and the efficiency with which this radiation is converted to biomass and grain.

\[
\text{Grain yield} = RIC_{\text{cum}} \times RUE \times HI
\]

Where, grain yield has units of g m\(^{-2}\), \( RIC_{\text{cum}} \) the cumulative intercepted solar radiation (MJm\(^{-2}\)) RUE the radiation use efficiency (g MJ\(^{-1}\)) and HI is the harvest index (g g\(^{-1}\)).
Techniques to harness solar radiation: Agriculture is both producer and consumer of energy. Agricultural production is found to be closely linked with direct and indirect energy inputs. The novel technologies are row orientation, canopy structure, crop density, crop combinations and cropping systems dictate extent of light use. For both sole crop and intercropping, it was found that the biomass of crops is positively correlated with radiation interception. Unlike sole cropping, intercrop RUE depends not only on crop canopy geometry but also on the intercropping arrangement. Row orientation either in NS or EW in maize and beans intercropping not influenced on light interception, radiation use efficiency and harvest index (Tsobo et al., 2001). Wheat, maize, sorghum and pearl millet recorded higher grain yields when sown in N-S row orientation compared to E-W orientation (Kler, 1988). RUE in wheat and triticale was lower (2.84 g/MJ) at high plant density of 400 seeds/m² and no change with medium (200 seeds/m²) and low plant density (100 seeds/m²). It also differs with crop combinations (Singer et al., 2007).

Radiation interception by crop canopies depends on LAI and the spatial distribution of leaf area (Watiki et al., 1993a). PAR interception and nutrient uptake were differed between component crops. The effects of nitrogen, Phosphorus (Fletcher et al., 2008; Jacob and Lawlor, 1991), water (Tesfaye et al., 2006), increased atmospheric CO₂ concentration (Manderscheid et al., 2003; Mulholland et al., 1998), and plant species (Sinclair and Muchow, 1999) on RUE was observed in many crops. Further, Mollier and Pellerin (1999) found a slight decrease in RUE in P deficient maize grown in a greenhouse. The response of RUE to N and P nutrition is species specific no effect of P in maize (Plenet et al., 2000) in contrast sunflower (Colombo et al., 1995) and wheat (Rodriguez et al., 2000), the RUE was influenced by P nutrition. In corn-cowpea intercropping, cowpea was more competitive than corn in absorbing divalent cations (Ca and Mg) for its high root cation exchange capacity, corn was more competitive than cowpea for P and K uptake. Low PAR interception and low P availability was affected by PAR interception (Eskandari et al., 2009).

Radiation interception is primarily determined by the LAI and an index of the efficiency of radiation interception, the crop extinction coefficient ‘k’ (Lizaso et al., 2003). ‘k’ values were calculated from measurements of transmitted PAR (µmol m⁻² s⁻¹), incident PAR (µmol m⁻² s⁻¹) and LAI on the date of sampling (Lindquist et al., 2005). In general, extinction coefficient of sorghum, rice and maize are 0.7, 0.65 and 0.84 respectively.

\[ \frac{TPAR}{IPAR} = \exp(k \text{LAI}) \]

-\ln k = \frac{PAR}{LAI}

The interpolated leaf area data were used with the daily solar radiation data (SR; MJ m⁻²) to estimate daily absorbed PAR using the equation (Wiegand et al. 1991)

\[ APAR = (0.45 \text{SR} [1 - R - T + RT]) \]

It assumes that the PAR reflected by the soil is negligible. Absorbed radiation (APAR) was accumulated daily in a particular period and regressed against the total above-ground dry matter (DM, g m⁻²) to calculate radiation use efficiency (RUE). Several other factors may have contributed to the low RUE during the early growth of these crops.

CONCLUSION

Solar radiation is an important resource for crop growth and development. The information across globe on RUE has revealed that LAI and solar radiation are most important factors influence crop growth. Leaf area dictates the quantum of light interception. Dry matter production is directly related to extent of IPAR. CO₂ assimilation rate, photosynthetic efficiency, specific leaf weight is resultant of light intensity. Crop mixtures always have higher RUE in addition to better utilization for land and time.

REFERENCES


