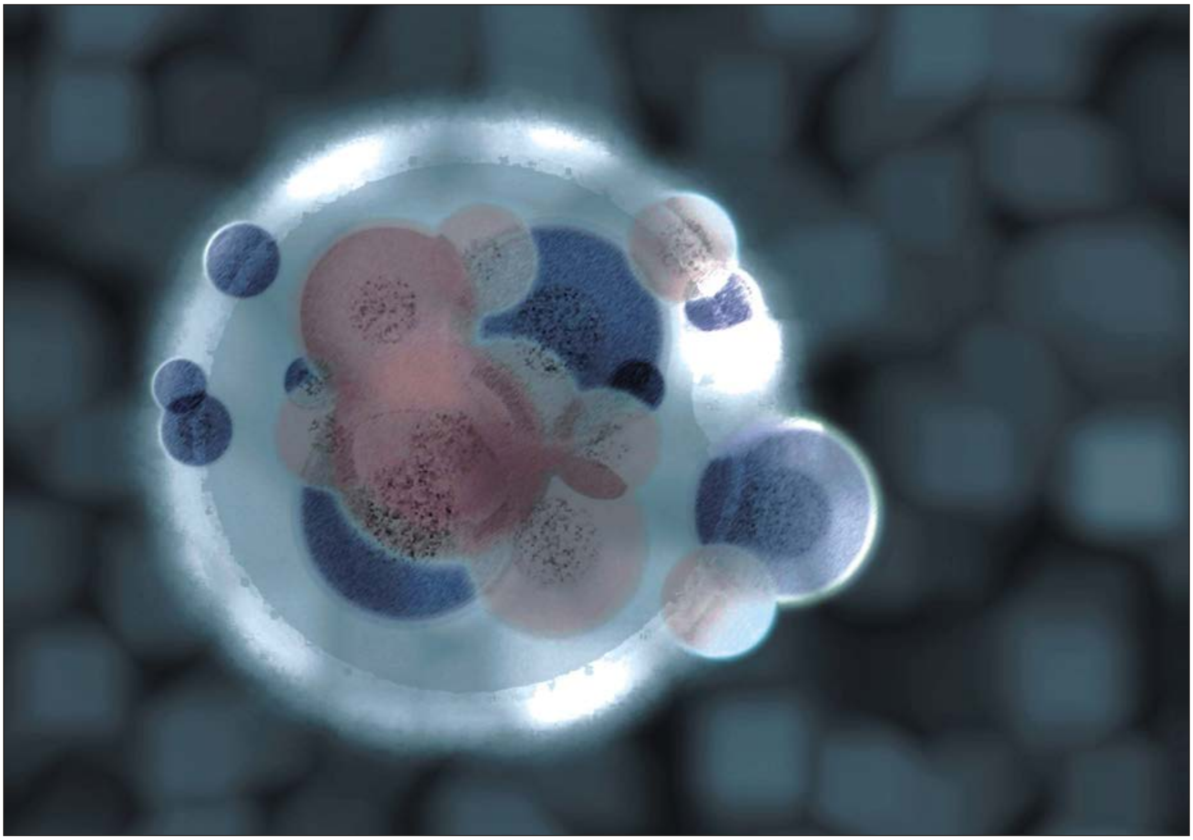

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Row Spacing Effects on Light Extinction Coefficients, Leaf Area Index, Leaf Area Index Affecting in Photosynthesis and Grain Yield of Corn (*Zea mays* L.) and Sunflower (*Helianthus annuus* L.)

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Abstract: In many crop models, light intercepted by a canopy (IPAR) is calculated from a Beer's Law equation: IPAR = PAR x [1 – exp (-k x LAI)], where k is the extinction coefficient, PAR the photosynthetically active radiation and LAI the leaf area index. The objectives of this research were to determine the effect of row spacing on light extinction coefficient (k), grain yield, LAI, LAIp for different row spacing of corn (*Zea mays* L.) and sunflower (*Helianthus annuus* L.). Seeds of the species were sown in rows 0.35, 0.50, 0.65, 0.80 and 1.00 m apart. Measurements of canopy light interception were taken near solar noon. The extinction coefficient showed a linear decrease as row spacing increased. For each crop, the effect of row spacing on k was described by one linear regression. Grain yield decreased for corn and sunflower as row spacing increased from 0.35 to 1 m. Leaf Area Index (LAI) and leaf area index affecting in photosynthesis (LAIp) was significantly increased by decreasing row spacing.

Key words: Corn, sunflower, row spacing, light extinction coefficient, grain yield

INTRODUCTION

Decreasing row spacing at equal plant densities produces a more equidistant plant distribution. This distribution decreases plant-to-plant competition for available water, nutrient and light and increases Radiation Interception (RI) and biomass production (Shibles and Weber, 1996). It also reduces the leaf area index required to intercept 95% of the incident radiation due to an increase in the light extinction coefficient (Francis *et al.*, 1996). However, the benefits of more equidistant spacing for crops grown with important water and nutrient deficiencies are variable. Some researchers reported grain yield increases (Andrade *et al.*, 2002; Board *et al.*, 1992), but others have not (Zaffaroni and Schneiter, 1989; Westgate *et al.*, 1997). There are times during the crop cycle that are most critical for yield determination. These times comprise the period bracketing flowering in maize (Kiniry and Ritchie, 1985) and sunflower (Connor and Sadras, 1992). An increase in light interception when row spacing is reduced has been reported for corn (Andrade *et al.*, 2002; Egharevba, 1975) and sunflower (Zaffaroni and Schneiter, 1989). The Beer's law equation estimates interception of solar radiation (IPAR) by a canopy as:

$$IPAR = PAR \times (1 - \exp(-K \times LAI)) \qquad (1)$$

where, PAR is the photosynthetically active radiation, k is the light extinction coefficient and LAI is the leaf area index (Francis *et al.*, 1996). Many crop models calculate light interception using Eq. 1 without adjusting k for row spacing effects (Jones and Kiniry, 1986). However, using an empirical Equation the model SORKAM (Rosenthal *et al.*, 1989) predicts greater light interception as row spacing decreases. More complicated approaches calculate light interception from the canopy architecture (usually plant height, plant width and an empirical coefficient to take in to account leaf display), the planting pattern and the solar angle (Boote and Loomis, 1991). Hence these models account for row spacing as a result of their construction.

Our objective was to relate k and row spacing in corn and sunflower with an empirical equation for each crop, so that models using Eq. 1 could account for the effect of row spacing on light interception equations, Grain yield, LAI (Leaf Area Index) and LAIp (Leaf Area Index affecting in photosynthesis) were derived from an experiment conducted with two crops at research station of Isfahan. This experiment compared k-values for the two species grown in five-row spacing at the same location, in the same year and with the same technique.

The extinction coefficients given in literature are mostly measured near solar noon. Thus the equations calculated from literature in this study accounted for the

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effect of row spacing on k around midday. The objective of the experiment conducted at Isfahan was to investigate effects of row spacing on light extinction coefficients, LAI, LAIp and grain yield of corn (*Zea mays* L.) and sunflower (*Helianthus annuus* L.).

MATERIALS AND METHODS

The experiment was conducted in 2006 at research station of Isfahan (32°30'N, 51°49'W). Before planting 100 kg N ha^{-1} and 50 kg P ha^{-1} were applied. Weeds were controlled by herbicides. No problems occurred with diseases or insects. Corn and sunflower seeds were planted 5 cm deep on 5 May 2006 in north-south rows. Plots were seeded to obtain the same population density for all row spacing for one species. Fifty percent emergence occurred on 12 May for sunflower and corn. Measurements were taken where the stand was even.

The plant population densities in these areas were 9 plants m^2 for corn and 8.6 plants m^2 for sunflower. The experimental design was a randomized complete block in a split-plot arrangement with four replicates. Each plot was 6 m long and 10.5 m wide. Plot treatment was crop species. Split-plot treatments were row spacing (0.35, 0.5, 0.65, 0.8 and 0.90 m). Within-row spacing is reported for each crop in Table 1.

Fraction of PAR intercepted was measured under clear skies using a luxmeter (model L×101 Lotran) at once time in every 10 days. Five measurements were taken above the canopy and 15 below on a 1 m section of row. There were two such readings in each split plot. Leaf area was measured on the same section of row and on the same date as light interception measurements.

Leaf area was estimated by passing leaves from 20% of the fresh weight of the plants through an area meter (LI-COR. Lincoln, NE, model 3000). The leaf area estimated by measuring a sub sample and the leaf areas of the whole sample were highly correlated (r^2 = 0.991 slop = 0.988).

The light extinction coefficient k was calculated from transmitted (TPAR) and incoming (PAR) data by

$$TPAR/PAR = \exp(-k \times LAI) \tag{2a}$$

Or

$$K = -\ln (TPAR/PAR)/LAI \tag{2b}$$

Table 1: Within-row spacing for corn and sunflower at five row spacing

Crop	Within-row spacing by row spacing (m) 0.35	0.5	0.65	0.8	1	Population density plants m^2
Corn	0.317	0.222	0.171	0.139	0.111	9.0
Sunflower	0.330	0.232	0.179	0.145	0.116	8.6

The extinction coefficient describes the angle of leaves to the sun and varies between 1 (completely perpendicular to the sun) and 0 (completely vertical to the sun). As defined, the angle between the sun and leaves depends upon the angle of leaves to the horizon and the angle of the sun to the horizon. Therefore we calculate LAIp (Leaf Area Index affecting in photosynthesis) in this study. The LAIp was calculated from product K-value with LAI:

$$LAIp = K \times LAI \tag{3}$$

Then physiological progress and development plant stage, gathered all products in every plot, which weighted with the exception of margins to obtain biological yield. Then sifting and cleaning so, seeds weighted to aim of grain yield.

Differences among treatments were tested by analysis of variance and were compared using Duncan's multiple range tests at the 0.05 level of significance.

RESULTS AND DISCUSSION

Row spacing effects on K: Figure 1 reports mean K-values observed at Isfahan for five row spacings and two crops. As expected according to pervious studies (Egharevba, 1975; Zaffaroni and Schneiter, 1989), for all two crops K-values significantly decreased with increasing row spacing from 0.35 to 1 m, indicating greater light interception efficiency in narrow rows. This improvement in light interception ability of the crops was probably the result of a more even distribution of the plants and hence of the foliage.

Extinction coefficients decreased by 27.7% for corn as row spacing increased from 0.35 to 1 m while it decreased by 31.4% for sunflower. Data from experiment were plotted against row spacing in Fig. 2. If row spacing

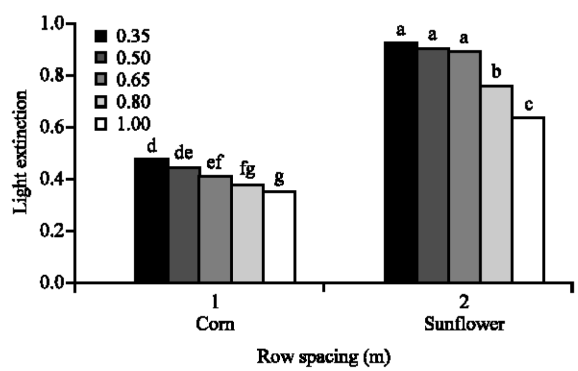

Fig. 1: The light extinction coefficient k for corn and sunflower as affected by five row spacing

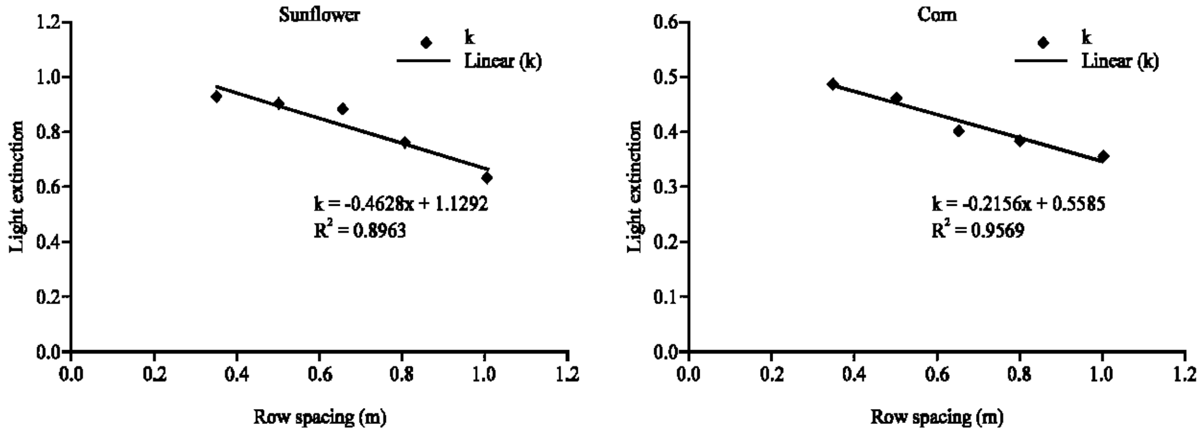

Fig. 2: Effect of row spacing (RS) on the light extinction coefficient k measured near solar noon for corn and sunflower

is set to a conventional value of 0.7 m, the regression equation predicts a K-value of 0.40 for corn and 0.80 for sunflower.

Most of the k-values used in crop modeling are similar to the values calculated by equation in Fig. 2. 0.44 (Francis *et al*., 1996) and 0.65 (Jones and Kiniry, 1986) for the corn, 0.9 (Kiniry and Ritchie, 1985) and 0.86 (Francis *et al*., 1996) for the sunflower.

The addition of another parameter to row spacing to account for the residual variation would be of great interest. Hiebsch *et al.* (1990) observed a greater integrated daily light interception in north-south rows than in east-west ones. Canopy height and width, which affect the size of the shadow cast and thus the ability of crops to intercept light (Boote and Loomis, 1991), may also be worth considering. However K-values reported in Fig. 2 determined from light interception measured with solar angle close to 90 (near solar noon during summer). When solar angle is 90°, row orientation and canopy height are unlikely to greatly affect the light extinction coefficient.

Thus, from the results available in literature, the choice of the most relevant parameter in not clear. Differences in K-value are difficult to interpret. Because k is a coefficient of an empirical equation that models a complex phenomenon more complex models may be more appropriate to simulate light interception when extinction coefficients are different from the values usually observed.

Row spacing effects on grain yield: Grain yield response was observed due to between row plant spacing variability (Table 2). It was lower at 1 m than at 0.35 m. Grain yield decreased by 3.26% for corn as row spacing increased from 0.35 to 1 m while it decreased by 4.99% for sunflower.

Table 2: Effect of row spacing on grain yield

	Grain yield by row spacing (m)				
Crop	0.35	0.5	0.65	0.8	1
Corn	7146a	7087ab	7029bc	6971cd	6913d
Sunflower	4641e	4582ef	4525fg	4467gh	4409h

All means followed by the same letter(s) are not significantly different at the 5% probability level

Most of the yield response of the crop to reductions in row distance was related to improvements in RI (Radiation interception) at the critical flowering period (Francis *et al*., 1996).

The effects of row spacing have been examined extensively in other crops. Such studies have been conducted on soybean [*Glycine max* (L.) Merr.] as early (Wiggans, 1939). Planting soybean in narrow row spacing can be advantageous. Costa *et al.* (1980) cited that, if available water and nutrients are adequate, then the factor that limits production is solar radiation. Thus, one reason for altering row spacing and plant arrangement is to improve light interception (Board *et al.*, 1992). Improved light interception occurs because Leaf Area Index (LAI) increases more rapidly in narrow row spacing, compared to wide row spacing. In addition, at similar plant densities, the time to reach critical LAI is reduced as row spacing decrease (Weber *et al.*, 2003). Heitholt *et al.* (1992) showed that narrow rows resulted in earlier canopy closure.

Row spacing effects on LAI and LAIp: Leaf Area Index (LAI) and Leaf Area Index affecting in photosynthesis (LAIp) was significantly increased by decreasing row spacing (Fig. 3). LAI and LAIp decreased by 4.74 and 31.22% for corn as row spacing increased from 0.35 to 1 m while it decreased by 4.37 and 34.50% for sunflower.

At the same plant densities, the time to reach critical LAI is reduced as row spacings decrease (Weber *et al.*,

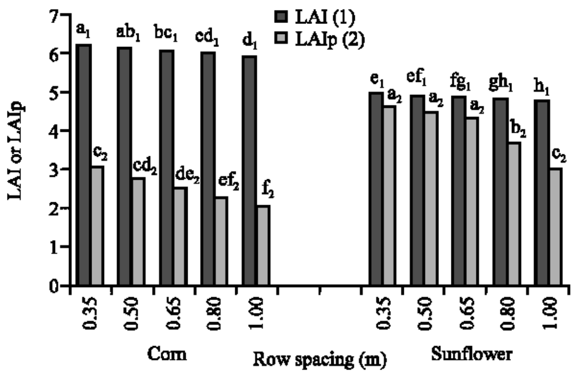

Fig. 3: Row spacing effects on LAI and LAIp (All means followed by the same letter are not significantly different at the 5% probability level)

2003). Hence, results indicate that the difference in dry matter accumulation due to within-row plant spacing variability is associated with seasonal interception of incident solar radiation. Plants are more evenly distributed when sown in narrower row spacing and the efficiency of light interception is improved. An increase in light interception when row spacing is reduced has been reported for corn (Egharevba, 1975) and sunflower (Zaffaroni and Schneiter, 1989). Greater light interception often increases yield (Karlen and Camp, 1985).

Narrowing row width is being used as a management tool to obtain a more uniform plant distribution in the field because current plant populations, especially for corn, have shown a positive linear yield respond to increasing plant populations (Farnham, 2001; Pedersen and Lauer, 2002).

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