Indian Journal of Agroforestry 28(1): 52-58 (2026)

Radiation interception, extinction coefficient of radiation and leaf area index of wheat under open and poplar plantation

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ABSTRACT: *Radiation interception plays a significant role in determining photosynthetic efficiency of crop as photosynthesis directly depends on interception of photosynthetically active radiation (PAR) and leaf area index (LAI). The present study was conducted during rabi season of 2023-24 at Research Farms of Department of Climate Change and Agricultural Meteorology and Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana. The experiment was laid out with split plot design incorporating three sowing dates (20th October, 5th November and 20th November) in main plots and three wheat varieties (PBW 826, HD 3086 and PBW 677) in sub plots. The PAR and LAI were monitored at regular intervals in both growing environments. PAR interception remained higher under open conditions by 20-29%, than under poplar plantation. The leaf area index was consistently recorded highest in first sowing, under both open and poplar plantations. Among the varieties, PBW 826 exhibited maximum LAI (4.80, 4.60) in open conditions and under poplar plantations than other varieties. The extinction coefficient (k) was comparatively higher under poplar plantation at both phenological stages in different treatments. The k value was maximum (0.60, 0.47) at anthesis and hard dough stage in third date of sowing followed by second and first date of sowing under poplar plantation. Among varieties, k value was maximum (0.55, 0.49) in PBW 677 followed by HD 3086 and PBW 826 at both phenological stages under poplar plantation. The relationship developed between PAR interception and LAI under both environments exhibited significant R^2 value (0.77 & 0.89).*

Research Article

ARTICLE INFO

Received: 10.01.2026

Accepted: 31.03.2026

Keywords:
*Wheat,
Leaf area index,
Photosynthetically active radiation,
Open conditions,
Poplar plantation*

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is a staple cereal crop in India, grown on 31.5 million hectares and producing 112.2 million metric tons of grain. The average yield is 3562 kg per hectare (Anonymous 2023). Wheat is mostly grown in the country's northern regions due to favourable climate conditions. Wheat is crucial for global food security, contributing nearly 20% of the total caloric and protein intake both domestically and worldwide (Shiferaw *et al.* 2013). The success of wheat cultivation in Punjab is largely attributed to fertile alluvial soils, assured irrigation facilities and widespread adoption of high-yielding varieties developed during the green revolution. The rice-wheat cropping system dominates region with wheat following rice as a principal winter crop. However, continuous mono-cropping and intensive resource use have led to emerging challenges such as declining soil fertility, groundwater depletion and reduced factor productivity. Indian agriculture has multiple challenges and limits, including rising demographic pressure, increased demand for feed, food and timber, the effects of climate change and natural resource degradation (Dhyani and Handa, 2013).

In recent years, alternative land-use systems such as agroforestry, including wheat-based tree-crop combinations, have been explored to enhance sustainability and diversify farm income. Understanding the growth dynamics and productivity of wheat under such systems is therefore essential for maintaining agricultural resilience in the region. Adopting intercropping with high-density, short-rotation tree species is an effective approach to meet the growing needs for food and industrial raw materials. This method also promotes the sustainable utilization of natural resources (Sarvade *et al.* 2014). Poplar (*Populus deltoides*) has become a significant species in agroforestry systems in various states of India, including Western Uttar Pradesh, Uttarakhand, Punjab, Haryana and Jammu & Kashmir (Joshi *et al.* 2024). Leaf fall in poplar trees begins in October, with approximately 13% of leaves shedding by end of the month. This figure rises to 27% by end of November and reaches 84% by end of December, though these

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percentages are climate-dependent. The trees typically lose all their leaves by January and February. New leaf growth starts in late March, with trees attaining full foliage by late April. In India, wheat is frequently grown alongside poplar in block plantings, serving as an important winter crop. Wheat yield declines by 10-46% with the age of poplar trees. However, the money from selling poplar wood at the completion of the rotation period usually offsets the yield loss (Chauhan *et al.* 2015). Wheat prefers relatively cold temperatures below 25°C and requires appropriate soil moisture throughout the growth season. In Punjab, the wheat growth season (October to April) coincides with seasons of low to high evaporative demand, sufficient sunshine and moderate to high solar radiation. Trees affect the microclimate by lowering photosynthetically active radiation (PAR) and air temperature while raising relative humidity (RH) in their underneath (Gill *et al.* 2016). It is evident that wheat grown under poplar-based agroforestry system receives less solar radiation due to canopy shading compared to open field conditions, leading to differences in radiation interception and extinction coefficient (k). Therefore, present study was planned to compare radiation interception, extinction coefficient and relationship between leaf area index (LAI) and PAR interception in both systems to understand the effect of poplar canopy on crop microclimate.

2. MATERIALS AND METHODS

2.1 Study Site

The study was conducted during the *rabi* season of 2023-24 at the Research Farms of the Department of Climate Change and Agricultural Meteorology and Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana. Ludhiana is located at a latitude of 30°54'N, a longitude of 75°48'E and an elevation of 247 meters above sea level. The city experiences a subtropical and semi-arid climate. In summer, particularly in May and June, temperatures often exceed 40°C, while winters in December and January can bring very cold conditions with temperatures occasionally dropping below 0°C. Ludhiana receives an annual average rainfall of 760 mm.

2.2 Experimental Details

Two field experiments were conducted using three wheat varieties (PBW 826, HD 3086, and PBW 677), with three sowing dates (October 20th, November 5th and November 20th) replicated thrice. The experiment was organized in split plot design. The sowing dates were kept in the main plots and wheat varieties were assigned to the sub-plots. The crop was raised in both experiments as per the recommendations given in the package of practices for *rabi* crops published by Punjab Agricultural University, Ludhiana.

2.3 Photosynthetically active radiation (PAR)

Hourly measurements of photosynthetically active radiation (PAR) were taken between 10:00 to 16:00 hours at the anthesis and hard dough stages. Utilizing a Line Quantum Sensor (Model LI-190 SB), the quantities of incoming, reflected and transmitted PAR were determined.

PAR interception (%) by the crop was calculated as:

$$\text{PAR interception (\%)} = \frac{\text{PAR (I)} - [\text{PAR (T)} + \text{PAR (R)}]}{\text{PAR (I)}} \times 100$$

Where,

PAR (I): PAR incoming above the canopy

PAR (T): PAR transmitted to the ground

PAR(R): PAR reflected from the canopy

2.4 Leaf Area Index

Leaf Area Index (LAI) was recorded at every 30 days interval starting 30 days after sowing with help of Sun Scan Plant canopy analyzer (LiCOR-make). The leaf area index was measured by placing the sensor once above the canopy followed by placing it at four different points below the crop canopy diagonally across the rows.

2.5 Extinction coefficient *(k)*

The light extinction coefficient (k) value was calculated using the following formula:

$$I = I_o \exp^{(-k*LAI)}$$

Where,

LAI : Leaf area index

I : Transmitted PAR

I_o : Incoming PAR

exp : base to the natural logarithms

k : Extinction co-efficient

$k = \{-\ln(I/I_o)\}/LAI$

2.6 Data Analysis

The data of PAR incoming, transmitted and reflected was recorded and converted to PAR interception for anthesis and hard dough stage. The LAI data was recorded and analysed by calculating averages of different values and presented graphically. Relationships were developed between LAI and PAR interception by pooling treatments (date of sowing and varieties) in wheat sown under open field conditions and poplar plantation conditions.

3. RESULTS AND DISCUSSION

3.1 Photosynthetically Active Radiation (PAR) interception

Photosynthetically active radiation (PAR) interception and its distribution within the crop canopy is important determinant of photosynthetic activity of the crop. The PAR interception by the canopy influences the leaf photosynthesis efficiency, which in turn effects the dry matter production and seed yield. Under normal conditions, interception of PAR and its utilization are low during early stages of crop growth. Solar radiation plays a vital role in photosynthesis. Photosynthetically Active Radiation (PAR) *viz.*, incoming, transmitted and reflected were recorded at different phenological stages of wheat crop. PAR interception in different wheat varieties under open and poplar plantation is presented for the anthesis and hard dough stages. The highest PAR interception was recorded at anthesis stage. The reason behind may be higher leaf area at that stage. The PAR interception was lowest during the hard dough stage across different sowing dates due to senescence of maximum leaves. Similar findings were observed by Sandhu (2015), PAR interception was variable at different phenological stages of wheat and PAR interception was lower at soft dough stage as compared to heading stage because LAI was higher during heading stage. The interception of PAR was maximum at 1300 hr, coinciding with the peak incidence of solar radiation. In open conditions, at anthesis stage, PAR interception was maximum (86.7%) for wheat sown on October 20^{th}, followed by November 5^{th} (82.7%) and November 20^{th} (77%) sown crop. While, under poplar plantation, during anthesis PAR interception was highest for wheat sown on October 20^{th} (65.5%), followed by wheat sown on November 5^{th} (61%) and November 20^{th} (56.4%) as presented in figure 1. Goutam *et al.* (2024) also reported that wheat sown on 20^{th} November recorded highest PAR interception (78.7%) as compared to crop sown on 30^{th} November, 10^{th} December and 20^{th} December, influencing wheat yield significantly. At the hard dough stage, the interception in open conditions was 78.5%, 75.5% and 71.4% for crops sown on October 20^{th}, November 5^{th} and November 20^{th}, respectively (Figure 2). In wheat sown under poplar plantation, PAR interception was 48.5% for October 20^{th} sown crop, 43.5% for November 5^{th} sown crop and 39.8% for November 20^{th} sown crop. Similarly, Wajid *et al.* (2004) also observed changes in PAR interception due to different sowing dates and varieties. They reported that wheat sown earlier had the highest PAR interception compared to wheat sown later, mainly because the earlier sown crop had a longer growing season.

PAR interception (%) under poplar plantation was less as compared to open field conditions both in case of different dates of sowing and different varieties due to canopy cover of poplar plantation that hindered the incoming radiation during different phenological stages. In open conditions, PAR interception was higher by (20-28%) compared to crop sown under poplar plantation. The incidence of direct radiation is comparatively less under poplar plantation. Similar results were observed by Singh *et al.* (2023). They observed that incident PAR was high (1280 Watt/m^2) in open as compared to the wheat crop grown under poplar plantation (910 Watt/ m^2).

Among different varieties, PAR interception was calculated and it was observed that PAR interception was highest in variety PBW 826 followed by HD 3086 and lowest in PBW 677. In open conditions, PBW 826 exhibited the highest interception (86.2%), followed by HD 3086 (83.2%) and PBW 677 (81.3%) at anthesis stage (Figure 3). While, under poplar plantation, during anthesis, PAR interception was maximum (63.8%) in PBW 826 followed by HD 3086 (60.4%) and PBW 677 (56.9%) as displayed in figure 3. In open conditions, at hard dough stage, PAR interception was recorded as 76.5% in PBW 826, 73.5% in HD 3086 and 70% in PBW 677, whereas under poplar plantation at same phenological stage, PAR interception was maximum (45%) in PBW 826 followed by HD 3086 (42.7%) and PBW 677 (40%) as presented in figure 4. It is evident that light interception within crop canopy is complicated and it is affected by sun angle, row direction, plant architecture, diffuse radiation and optical properties of leaves (Xue *et al.* 2015).

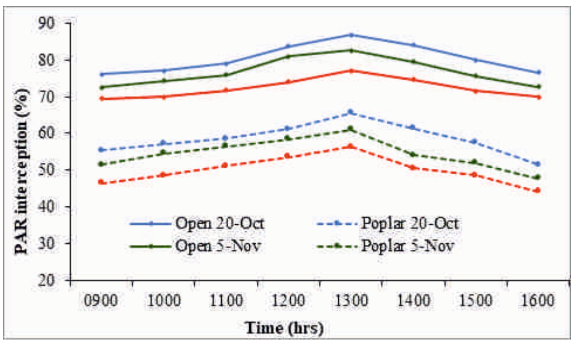

Fig. 1: PAR interception at anthesis stage in different dates of sowing under open and poplar plantation

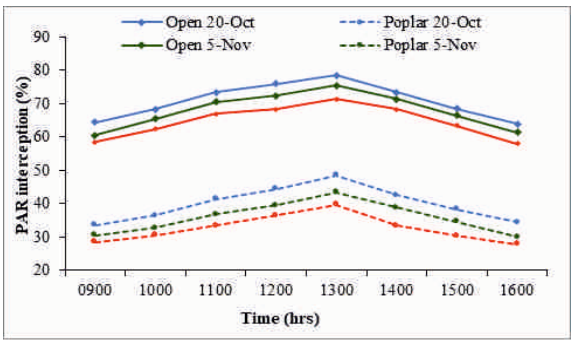

Fig. 2: PAR interception at hard dough stage in different dates of sowing under open and poplar plantation

3.2 Leaf area index (LAI)

Leaf area is one of the important growth characteristics which play important role in radiation interception and yield of crop. It is an inventory of the population of leaves that are absorbing light and momentum and exchanging heat, moisture, CO_2 and trace gases with the atmosphere. The leaf area index (LAI) controls the amount of intercepted PAR and hence photosynthesis (Smith *et al.* 1991). From a micrometeorological perspective an increase in leaf area index increases light interception and the source/sink strength for heat, water and CO_2 exchange. In different treatments, leaf area index (LAI) was lower during the initial stages of crop growth and increased as crop developed and was recorded maximum at 90 days after sowing (DAS). After this peak, the LAI gradually decreased as the crop approached senescence and maturity. The highest LAI (4.80) under open conditions was recorded at 90 DAS for October 20th sowing, followed by November 5th (4.68) and November 20th (4.51) sowing in variety PBW 826 (Figure 5a). Mehta (2020) also observed similar results. She reported that the leaf area index (LAI) was initially low during the early stages of crop growth but increased as the crop developed. It peaked at 90 days after sowing (DAS) and then gradually declined as the crop entered the senescence and maturity stages.

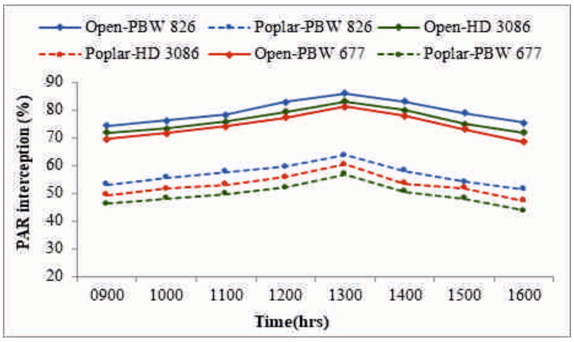

Fig. 3: PAR interception at anthesis stage in different varieties under open and poplar plantation

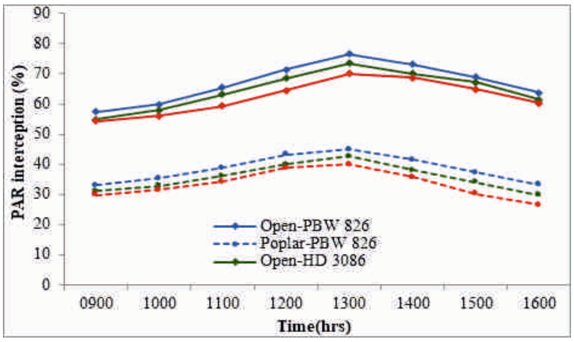

Fig. 4: PAR interception at hard dough stage in different varieties under open and poplar plantation

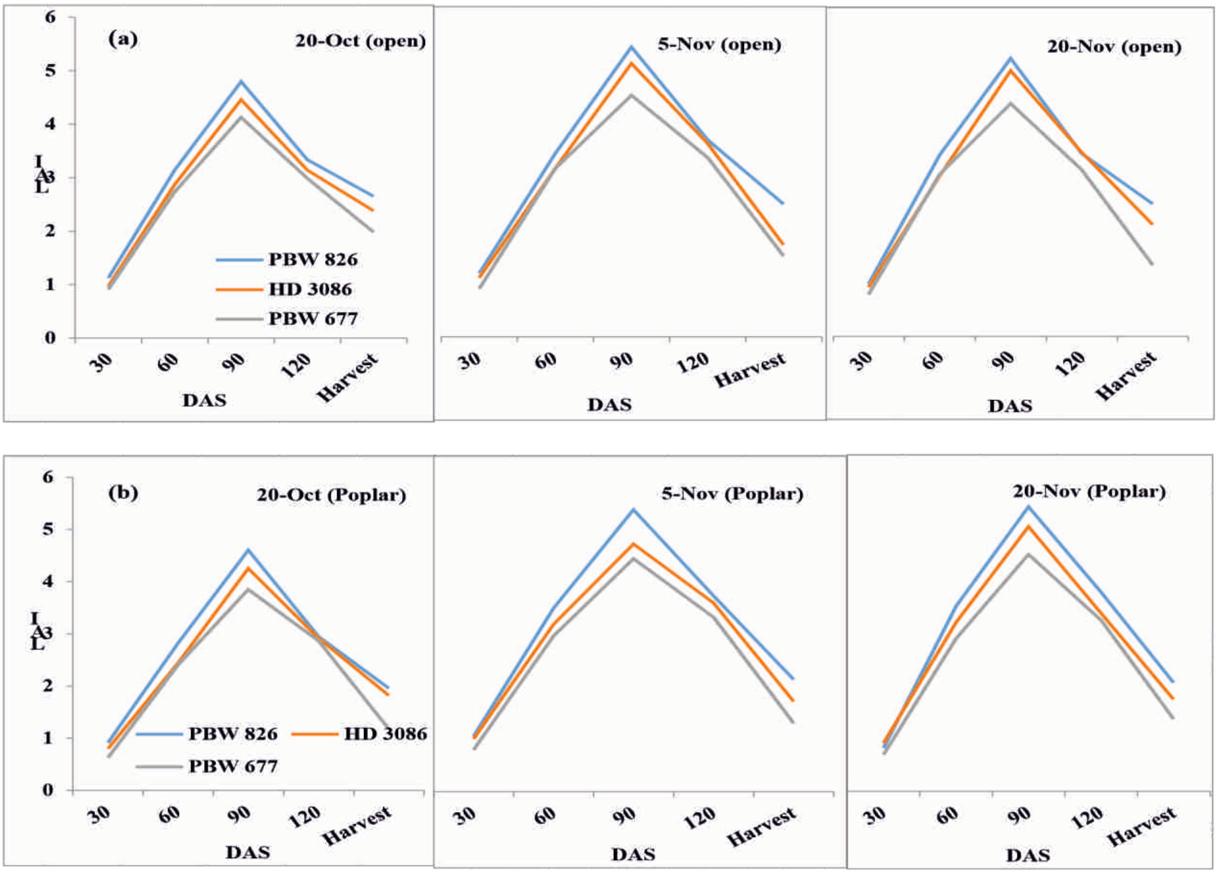

Fig. 5: LAI of Wheat varieties under open conditions (a) and poplar planation (b)

Under poplar plantation, the maximum LAI (4.60) was observed at 90 DAS for October 20th sowing followed by the November 5th (4.48) and November 20th (4.06) sowing as shown in figure 5(b). Similarly, Kamrozzaman *et al.* (2016) and Dubey *et al.* (2019) also observed that early sowing results in a higher leaf area index (LAI) compared to late sowing. Similarly, Gupta *et al.* (2017) proposed that delayed sowing diminishes leaf area, potentially due to a reduced photosynthetic rate and poor leaf development, leading to a lower LAI. Farooq *et al.* (2009) reported that high-temperature stress associated with late sowing decreases the leaf area index, which in turn reduces the water potential and relative water content in leaves, ultimately diminishing photosynthetic productivity. Among the different varieties, the LAI was significantly higher in PBW 826, followed by HD 3086 and PBW 677 under different treatments. Singh *et al.* (2025) also observed that LAI, plant height of wheat also varies in different varieties.

3.3 Relationship between PAR interception and LAI

Crop growth can be analyzed in terms of its efficiency to use intercepted radiations. This approach has been applied to many field crops (Hussain *et al.* 2002).The relationship has been used as a basis for theoretical investigations into tropical crop productivity, modelling climate effects and the importance of light as a limiting factor in crop performance (Monteith 1981). Leaf area index (LAI) increases with an increase in crop age and declines at maturity due to senescence of leaves. The per cent PAR interception varied with the leaf area index (LAI). The maximum PAR interception was recorded when LAI was highest. The leaf area index of wheat was higher under open plantation as compared to wheat grown under poplar plantation. When crop was approaching to maturity, the leaf area decreased considerably. The relationships were developed between LAI and PAR interception and are presented in figures 6 & 7 for open and poplar plantation, respectively. Regression equations were developed between PAR interception and LAI. Linear regression equations showed good results for both environments. For wheat grown under open conditions, R^2 value was estimated as 0.77 that means 77 per cent variability in leaf area index was due to PAR interception. Similarly, Mukherjee *et al.* (2012) also observed the positive relationship between LAI and PAR interception under Punjab conditions. Whereas, under poplar planted wheat, R^2 value was estimated as 0.89 that means 89 per cent variability in leaf area index was due to PAR interception. Similarly, Goutam *et al.* (2024) also observed significant relationship of PAR with LAI of wheat.

3.4 Extinction coefficient

Extinction coefficient (k) determines the ability of the canopy to utilize the radiation falling on the crop. The k value is relatively higher in sparse crop due to more light attenuation at base whereas in dense crop canopies less light is attenuated at the base due to profuse foliage. The extinction coefficient was calculated for anthesis and hard dough stage of wheat under open and poplar plantation in different treatments. It was observed that k value was minimum (0.53) at anthesis stage in first date of sowing and increased with delay in sowing under open conditions (Figure 8). At hard dough stage, extinction coefficient decreased as displayed in figure 9. Similarly, Dhakar *et al.* (2023) also reported that the delayed sowing caused increase in extinction coefficient. The value of 'k' decreases with advancement in crop growth. They reported that it was lowest at physiological maturity (0.43) while maximum at jointing stage in all the cultivars (0.62). Among varieties, k value was maximum (0.55) in variety PBW 677 followed by HD 3086 and PBW 826. The extinction coefficient depends on the density/foliage of crop and in case of PBW 826, more leaf area of crop lead to lesser rate of radiation diminishing. The k value for wheat varies between 0.37 and 0.82 (Muurinen and Peltonen-Sainio, 2006). The k value was comparatively lower under open conditions than poplar plantation at both

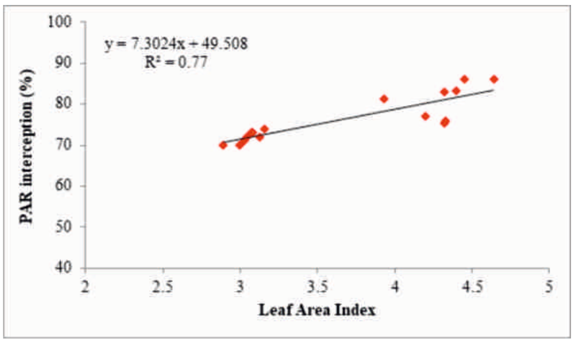

Fig. 6: Relationship between PAR interception and LAI of wheat under open conditions

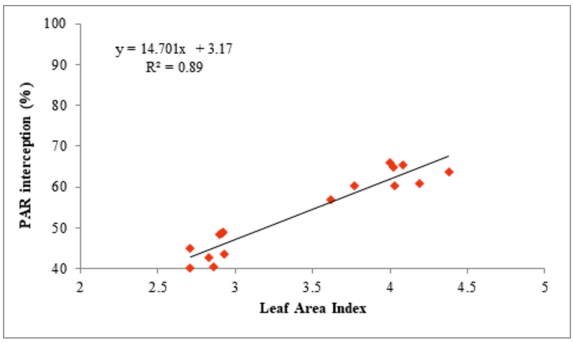

Fig. 7: Relationship between PAR interception and LAI of wheat under poplar plantation

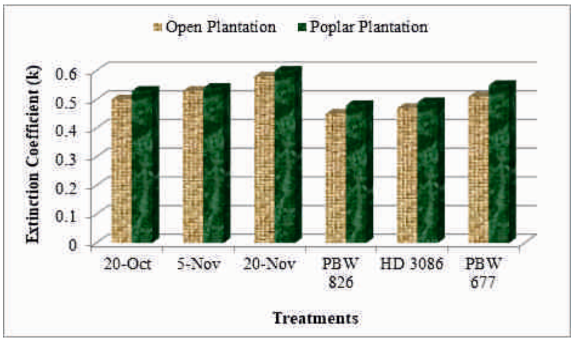

Fig. 8. Extinction Coefficient at anthesis stage in wheat under different treatments

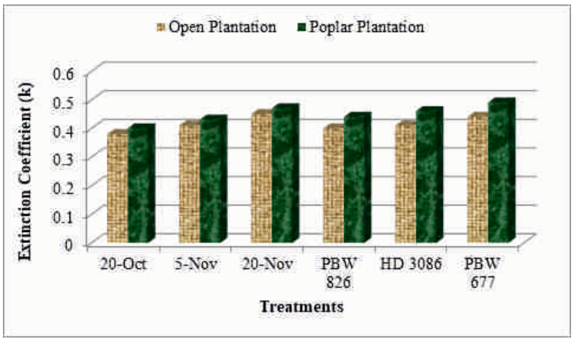

Fig. 9. Extinction Coefficient at hard dough stage in wheat under different treatments

phenological stages in different treatments. But the variability in extinction coefficient was not much significant under different environments. The findings are in corroboration with results of Meena *et al.* (2022). They also observed and concluded that extinction coefficient in wheat didn't vary much under different tillage and irrigation regimes.

4. CONCLUSION

PAR interception remained higher under open conditions by 20-28%, than under poplar plantation. The leaf area index was consistently recorded highest in first sowing, under both open and poplar plantations. Among the varieties, PBW 826 exhibited the highest LAI in open conditions and under poplar plantations, outperforming HD 3086 and PBW 677 across all conditions. The extinction coefficient (k) was 5.7% and 13.8% more in third date of sowing than second and first date of sowing, respectively under open conditions. Whereas, under poplar plantation, extinction coefficient (k) was 10% and 12% more in third date of sowing than second and first date of sowing, respectively. Among varieties k value was maximum (0.55, 0.49) in variety PBW 677 followed by HD 3086 and PBW 826 at both growth stages under poplar plantation. The k value was comparatively lower under open conditions at both phenological stages in different treatments. The main reason behind this was less dense foliage under poplar plantation due to lesser radiation interception. The relationship developed between PAR interception and LAI under both environments exhibited significant R^2 value (0.77 & 0.89). The findings indicated that radiation interception and its attenuation to the base of plant are uniquely dependent on the crop density.

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