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Impacts of artificial light at night on the vegetative growth and yield attributes of fodder oat (*Avena sativa*)

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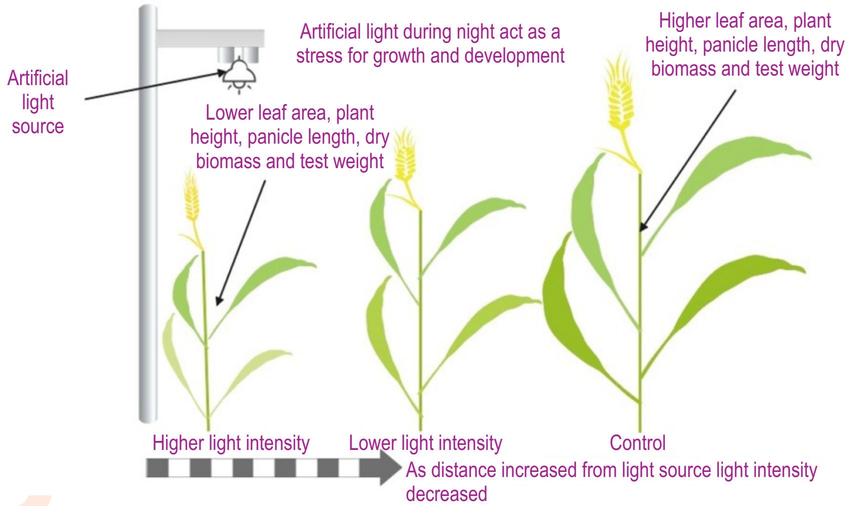
Abstract

Aim: The present investigation was designed to study the impact of artificial light at night on the phenological phases and yield contributing traits of fodder oat variety Kent for holistic breeding along the roadsides or highways.

Methodology: The experiment was conducted at Central Research Farm of ICAR-IGFRI, Jhansi, India, in a plot under natural conditions. The treatment Lc (controlled) was under natural conditions receiving normal daylight and dark periods. However, treatment L1 (300-350 lux), L2 (200-300 lux), L3 (100-200 lux), and L4 (10-50 lux) were different light affected areas having distances 0, 5, 10, and 15 m from the light source. Duncan's test, OPSTAT, and SPSS version 16.0 software were used for statistical analysis.



Results: The vegetative growth parameters such as plant height, total leaf area, flag leaf area, days to 50% flowering, panicle length, total dry biomass, and test weight were increased linearly as the distance increased from the artificial light source (minimum value for L1 treatment and maximum for Lc). However, plant population per meter square was maximum for L1 treatment and minimum for local control (Lc; no night light effect). Moreover, it is the first report of artificial light at night on the fodder oat from India and concluded that night light significantly affects the plant phenology and yield potential, and opens a new research paradigm on plant-artificial light at night interactions.

Interpretation: Plants close to the light source received maximum intensity of night light (L1) than distantly located treatments (L2, L3, and L4). Artificial light at night-time had adverse effects on the yield-contributing traits and showed a significant negative relationship.

Key words: Artificial light, Fodder oat, Light intensity, Morphological traits, Night time

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Introduction

Light (natural and artificial) is an important environmental factor influencing plant growth and development; therefore, it is crucial for sustaining life on the earth. Sunlight is a central regulator of microorganisms' ecological, physiological, and behavioral functions, including plants (Kami *et al.,* 2010; Sanders *et al.,* 2021). In plants, it is well documented that light controls the chlorophyll synthesis, photosynthesis, leaf formation, growth movements such as photoperiodic movements, phototropism, seed germination in photoblastic seeds, circadian movements and flowering rhythms (Singhal *et al.,* 2017; Gaston *et al.,* 2017; Bose *et al.,* 2018). Plants are adapted to dark and light period (diurnal period) for millions of years and perform best under natural diurnal fluctuating conditions. However, the industrial revolution and different human development activities generate novel pollutants such as micro-plastic, electronic waste, heavy metals, and greenhouse gases (Maiti and Chowdhury, 2013), drastically affecting environmental balance and sustainability.

Artificial light at night is a significant anthropogenic pollutant that has increased with modern human lifestyles and disrupts microorganisms' natural diurnal cycle, including plants. (Knop *et al.,* 2017; Singhal *et al.,* 2021). Excess artificial light at night has increased promptly during the last decades due to increased urbanization and public safety; and poised serious matter of artificial or ecological night light pollution (Longcore and Rich, 2004). Artificial night light pollution can be defined as an area receiving any amount of artificial light during night-time. However, light brightness of more than 3000 µcd m^{-2} is considered as a light-polluted area. According to a new global map of artificial light at night brightness based on high-resolution satellite data, more than 80% of the world's population and 23% of its surface area live in artificial light at night levels above the threshold level. Light pollution is increasing at a geometric rate of 6% per year, though it varies on a spatial and temporal basis. For example, Singapore and San Marino have near-total light populated areas (Falchi *et al.,* 2016; Kyba, 2018), and some areas receive artificial light all night, such as roads and streets, while others receive it for only few hours, such as home. In recent years, few studies have been undertaken to examine the impact of artificial light at night on plant developmental processes, and it has been discovered that it primarily hinders the plant functions, with few exceptions, such as alleviating the impact of lead in the freshwater ecosystem (Gaston *et al.,* 2015; Pu *et al.,* 2019).

Seed germination, leaf growth, photosynthesis, and, most important, the photoperiodic and circadian rhythms of flowering plants are affected by artificial light (Bennie *et al.,* 2016; Singhal *et al.,* 2018; Sodani *et al.,* 2021). It also functions as a severe stressor during plant phenological stages, affecting seed germination, seedling establishment, and biochemical condition of rice seedlings in their early stages (Singhal *et al.,* 2019). Consequently, Viera-Pérez et al. (2019) reported that artificial light between 600-700 nm primarily affects the reproductive cycle in *Traganum moquinii* and reduces the number of flowers and, thereby, seed production. Similarly, an artificial light of 16 to 24 lux influenced the biorhythm of *Acer pseudoplatanus* and *Rhus typhina*, delaying the commencement of autumn vegetative phenological phases at crown portions, leaf colouring, and leaf fall by 13 to 22, 6 to 9 and 6 to 7 days, respectively (Škvareninová *et al.,* 2017). Recently, Meravi and Prajapati (2020) found that artificial night lights with light intensity 340 to 360 lux influence the photosynthetic efficiency, affecting the photochemical yield and quantum yield of tree species. Therefore, the present investigation was designed to explore the effect of artificial light at night on the phenological, morphological and yield contributing traits of fodder oat that greatly affect fodder productivity. Understanding the relationship between artificial light at night and plants phenological stages could be rewarding for plant breeders to develop cultivars that could be grown on roadsides or highways without yield penalty.

Materials and Methods

Plant material and Experimental design: In the present study, a fodder oat (*Avena sativa* L.) variety Kent, predominantly cultivated as a fodder oat variety in India was selected as a test genotype. The trial was conducted at Central Research Farm of ICAR-IGFRI, Jhansi, India during *rabi* 2019-20 (from mid-October to mid-May) in plot bases under natural conditions. The row to row and plant to plant distances were 50 and 5 cm, respectively, apart. All agricultural operations from sowing to harvest were applied timely and as per the prescribed standard package of practices of fodder oat crop (Ahmed *et al.,* 2017). During night, the light meter (Lux meter) detects 300-350 lux (at 0 m distance from the source) to 10-50 lux (at 15 m distance; intensity decreases with the distance from the artificial light source) light from an artificial light source installed at 15 m height consisting of white light-emitting diode (LED) 100 V (blue light rich) covering approximately 15 m^2 of the field. The treatment Lc (controlled) was under natural conditions receiving normal light and dark periods. However, treatment L_1 (300-350 lux), L_2 (200-300 lux), L_3 (100-200 lux), and L_4 (10-50 lux) were different light affected areas having distances 0, 5, 10, and 15 m from the light source. Different yield attributing parameters such as days to 50% flowering (days), plant height (cm), plant population m^{-2}, flag leaf length (cm), flag leaf width (cm), total leaf area (cm^2), panicle length (cm), dry biomass (g), seeds $panicle^{-1}$ and test weight $plant^{-1}$ (g) were recorded manually using scale and weighing machine.

Data recording and Statistical analysis: Days to 50% flowering was measured on a whole plot basis whereas other traits were recorded selecting 10 random plants from each plot. Mean values of days to 50% flowering, plant height, plant population m^{-2}, flag leaf length and width, total leaf area, panicle length, dry biomass, seeds $panicle^{-1}$ and test weight per plant were taken from each treatment of three independent replications. Significant differences among various treatments were determined using Duncan's test. Statistical Package for Social Science (SPSS Version 16.0) and OPSTAT software (Sheoran *et al.,* 1998) was used for statistical analysis.

Results and Discussion

Light is a key factor in regulating several physiological functions and pathways in plants and plays a vital role in regulating diurnal cycles and biological rhythms (Sanchez *et al.,* 2020). In the present study, the impact of artificial light at night on the oat phenology was studied and elaborately concluded that artificial lights during night time act as a stressor and stimulus to early flowering and maturity. The analysis of variance (ANOVA) for eight traits showed highly significant variation at treatment levels for all the studied traits, except plant height (Table 1). The mean value of vegetative growth parameters was recorded at 50% flowering and is represented in Fig. 1. Plant height is considered an important agronomical trait as forage crops are concerned due to more biomass (green and dry) production and represents plant stature and growth under different environmental regimes (Chauhan *et al.,* 2021; Chand *et al.*, 2022).

Plant height of Kent variety was observed maximum under control condition (Lc: 160.80 cm) whereas the minimum was in L1 (150.80 cm). Interestingly, plant height increased as the distance from light source increased. For example, treatments L2, L3, and L4 have recoded a plant height of 153.40, 154.80, 157.00 cm, respectively, at 50% flowering stage. Previous studies suggest that artificial light at night affects gibberellin biosynthesis pathway in plants regulating plant height and increased artificial light reduces plant height (Fernandez *et al.,* 2009; Jiang *et al.,* 2021). Plant population represents crop growth and vigor under various environmental conditions (Willey, 2018). For instance, a lower plant population m^{-2} represents better and profuse growth and development of plants. Plant population m^{-2} was observed highest in L1 (107.00), whereas lowest in Lc (76.60); however, it decreased with increased distance from the light source in treatment L2, L3, and L4, respectively. A similar type of result was observed in *Paphiopedilum* orchid seedling where they found a compact plant with shorter leaf length and width under blue LED as compared to control (Lee *et al.,* 2009). Flag leaf area is important for enhancing photosynthesis during late reproductive phases and increasing the accumulated biomass in fodder crops. The highest and lowest flag leaf area was reported in Lc (57.4 cm^2) and L1 (29 cm^2), respectively; however, it increased with the increased distances from the light source. Likewise, total leaf area, representing the full-fledged growth of vegetative phase, was reported highest in Lc (96.6 cm^2) and lowest in L1 (63.8 cm^2), respectively; however, it increased with the increased distance from the light source. Similarly, blue light with a high red/far red ratio inhibited stem elongation and decreased leaf area in tomato, lettuce and chrysanthemum (Oyaert *et al.,* 1999).

The present investigation concluded that artificial light at night reduces the plant height, flag leaf length and width, and total leaf area, which are crucial for vigorous vegetative plant growth and reproductive phases. Therefore, artificial light is a substantial stress inducer for developing the vegetative and reproductive phases (Hey *et al.,* 2020). These results support the hypothesis of Singhal *et al.* (2019), where artificial light during night-time acts as a stressor and is responsible for oxidative stress and reduce the

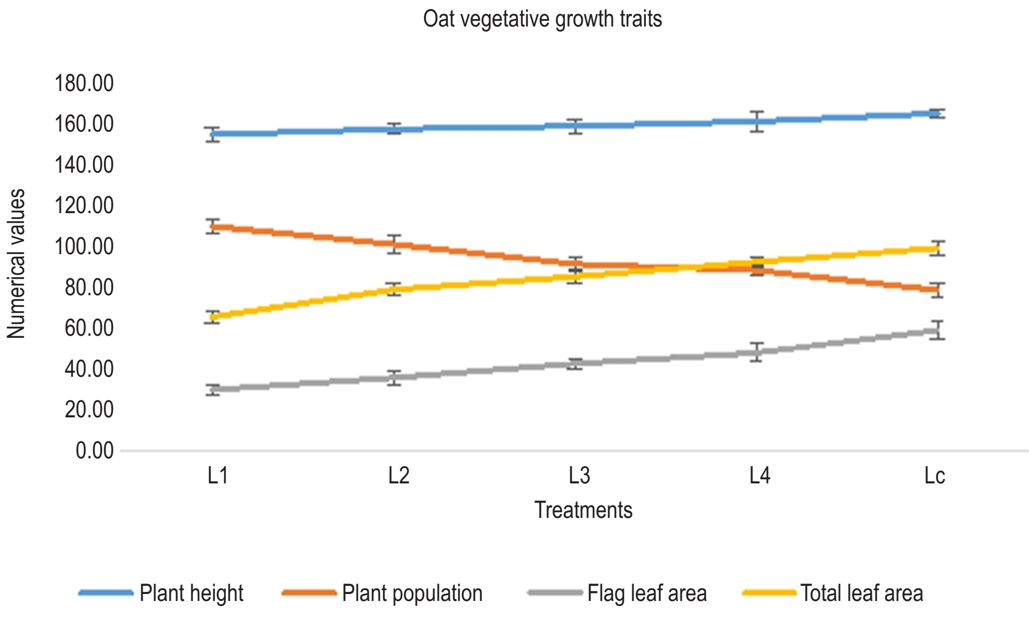

Fig. 1: Effects of artificial light at night on different vegetative growth parameters of oat at different treatments. It represents the mean value of plant height (cm), flag leaf area (cm^2 $plant^{-1}$), total leaf area (cm^2 $plant^{-1}$), and standard deviation used as an error bar for each treatment.

Table 1: Analysis of variance (ANOVA) and simple descriptive variability parameters for morphological contributing traits among five different treatments in fodder oat

	Mean sum of squares[@]			Variable parameters[$]					
Characters[#]	**Replication (2)**	**Treatment (4)**	**Error (8)**	**Range**	**Mean**	**±SE (m)**	**± SE (d)**	**CD**	**CV**
PH	4.03	42.46	11.80	147-163	155.45	1.98	2.80	N/A	2.21
PP	11.40	407.57*	10.82	74-110	91.40	1.90	2.69	6.29	3.60
FLA	14.60	359.93*	7.93	26-61	41.80	1.63	2.30	5.39	6.74
TLA	51.20	483.5*	1.70	61-101	82.00	0.75	1.07	2.49	1.59
DTF	0.87	130.90*	2.20	67-86	76.07	0.86	1.21	2.84	1.95
PL	6.07	56.83*	1.98	24-39	31.33	0.81	1.15	2.69	4.50
DBM	2.47	51.60*	2.55	38-53	44.53	0.92	1.30	3.05	3.59
S/P	3.27	28.40*	1.350	38-48	43.93	0.67	0.95	2.22	2.65
TW	1.04	25.91*	1.61	13-23	16.78	0.73	1.04	2.43	2.58

[@]Figure under parenthesis represents degree of freedom; *Significant at 5% level of significance. [#]PH-Plant height, PP-Plant population m^{-2}, FLA-Flag leaf area, TLA-Total leaf area plant^{-1}, DTF-Days to 50% flowering, PL-Panicle length, DBM-Dry biomass, S/P-Seed panicle^{-1}, TW-Test weight. [$]CD-Critical difference at 5% level of significance, SE (m)-Standard error of mean, SE (d)-Standard error of difference, CV-Coefficient of variation

Table 2: Impact of street light at night on yield attributing traits (post-anthesis) of oat under different light regimes

Treatment*	**Days to 50% flowering (days)**	**Panicle length (cm)**	**Dry biomass (g)**	**Seed per panicle**	**Test weight (g)**
L1	$67.6^{a}\pm0.58$	$26.0^{a}\pm1.73$	$39.67^{a}\pm1.53$	$39.3^{a}\pm1.53$	$13.8^{a}\pm1.26$
L2	$72.4^{b}\pm1.53$	$29.0^{b}\pm2.00$	$41.6^{a}\pm1.15$	$43.0^{a,b}\pm1.00$	$14.8^{a,b}\pm0.95$
L3	$75.4^{c}\pm0.58$	$31.3^{b,c}\pm1.53$	$44.6^{b}\pm0.58$	$44.0^{b}\pm1.00$	$16.0^{b,c}\pm1.15$
L4	$80.6^{d}\pm2.08$	$32.7^{c}\pm1.53$	$46.3^{b}\pm1.53$	$46.0^{b,c}\pm1.73$	$17.7^{c}\pm1.46$
Lc	$84.6^{e}\pm1.53$	$37.6^{d}\pm1.53$	$50.33^{c}\pm2.52$	$47.3^{c}\pm1.15$	$21.3^{d}\pm1.26$

*L1 (300-350lux), L2 (200-300lux), L3 (100-200lux), L4 (10-50lux) and Lc (Control, and No night light pollution)

dark recovery from daily stresses. Further, increased plant population (plant m^{-2}) under light-polluted regimes showed weak performance of plants due to minimal space between plants, leads to more competition for natural resources (water, nutrients, light, etc.); in contrast to a controlled condition where reduced plant population was healthy and vigorous (Ouzounis *et al.,* 2015). Days to 50% flowering is an important trait that represents the beginning of a reproductive phase of the plant and is most sensitive to light during the night period. Maximum and minimum days to 50% flowering were observed in Lc (84.60 days) and L1 (67.60 days), respectively, and consequently increased with the increased distance from the light source.

Panicle length (cm), seed per panicle, dry biomass (g), and test weight (g) are important yield contributing traits and directly influence the final yield potential of the crop. Panicle length significantly contributes to seed yield in oat; however, its growth is hampered by artificial light at night. Maximum and minimum values of panicle length were reported in Lc (37.63 cm) and L1 (26 cm) conditions, respectively. The panicle length decreased as distance from light sources increased. Similarly, the maximum total dry biomass was recorded in Lc (50.3g) and minimum in L1 (39.7g); however, it increased as the distance from the light source increased. Likewise, seed per panicle represents the seed carrying capacity of the plant, and the highest number of seeds per panicle were recorded for Lc (47.3) and lowest for L1 (39.3) treatment. Test weight represents seed growth and decides the yield potential of any crop. It is presumed that good seed weight directly correlates with the seed yield and healthy seedlings in the next generation. The highest test weight was recorded for Lc (21.3g) and lowest for L1 (13.8g) treatment.

The test weight also increased as the distance from the light source increased. Moreover, these yield contributing attributes improved as the distance from the light source increased, and the statistical data of these traits are shown in Table 2. The artificial light at night affects the oat crop phenology at various stages such as flower initiation, 50% flowering, and physiological maturity. The present investigation highlighted that artificial light at night speeds up plants' phenological stages stages, altering various biochemical pathways, resulting in yield penalty (Monostori *et al.,* 2018; Fiutak and Michalczyk, 2020). Similarly, Bennie *et al.* (2018) studied artificial light at night on the grassland vegetation and reported 7-12 days earlier flowering than control. In contrast, Chen *et al.* (2009) reported a delayed flowering in soybean under artificial night light conditions. However, oat is a long day crop whereas soybean is a short-day crop that enhances critical day length in oat. Besides, early

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flowering might be possible due to extra light factors that contribute to reduced growing degree days (minimum days required to change from one stage to another) by night light or advancement of phenological stages (Viera-Pérez *et al.,* 2019). Similarly, panicle length, seed per panicle, test weight, and dry biomass were negatively associated with artificial night light conditions. Artificial light during night-time acts as a stressor for plants, impede resource allocation to reproductive organs, and reduces source capacity due to reduced flag leaf area (Lian *et al.,* 2021; Wilson *et al.,* 2021). It adversely affects plants' potential production or primary producers because of more allocation's losses in respiration maintenance (Grubisic *et al.,* 2017; Fukuda, 2019). Thus, the study highlighted that high artificial-night-light areas had reduced seed and fodder yield of oat compared to low or reduced artificial night light conditions and maximum gain was under natural diurnal cycle. However, the relationship of plant growth and development with artificial night light has not been clearly illustrated at the molecular, biochemical, and cellular levels till today.

The findings of the present investigation could be used for speed breeding to accelerate breeding cycles and select artificial night light insensitive or tolerant crop cultivars that could be grown near highways and roadsides for better fodder production. Further, the analysis also presented adverse effects of artificial night light on fodder oat. Artificial night-light affects the physiological, biochemical and flowering process of plants that can decide the yield potential of agricultural crops in the near future. Also, the present investigation highlighted the impact of artificial night light on the phenological traits of fodder oat that would be remarkable to understand the behavioural relationship between them. In the end, it would help plant breeders to develop night light tolerant cultivars, policymakers to design and frame highway light policy (duration, intensity, type of light, etc.), and farmers to select suitable crops to minimise the drastic effect of artificial light at night.

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Add-on Information

Authors' contribution: R.K. Singhal: Data collection, field management, writing MS; **Indu:** Experimental design, data interpretation; **S. Ahmed:** Experimental design, field management; **S. Chand:** Experimental design, statistical analysis, revision of MS; **M. Rana:** Field management; **N. Kumar:** revision of MS; **P. Priyadarshini:** Data interpretation.

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