Effect of windbreaks (*Casuarina equisetifolia* L.) on productivity of paddy in South Gujarat

ABSTRACT

The intentional integration of trees into an agroecosystem results in agroforestry practices such as windbreak, which simultaneously help the economy, the environment, and society. It is a crucial tool for safeguarding agricultural land and boosting crop productivity. An investigation was therefore conducted to determine the impact of windbreaks (*Casuarina equisetifolia* L.) on paddy productivity in South Gujarat. In the current study, we found that environmental competition caused paddy growth and production to decrease close to the Casuarina windbreak. The impact of the windbreaks on paddy growth and yield became positive, and the continuously increased distance from the windbreaks reached its maximum at 17 m (Plant height 97.34 cm, number of tillers per plant 11.17, total fresh weight plant 17,799 kg ha^{-1}, dry straw weight 6,577 kg ha^{-1} and grain yield 4,103 kg ha^{-1}) and then gradually decreased (plant height 83 cm, tillers per plant 8.17, total fresh weight plant 12,315 kg ha^{-1}, dry straw weight 4,855 kg ha^{-1} and grain yield 3,101 kg ha^{-1}). The wind velocity maximum (4.57 km hr-1) close to windbreaks exhibits an opposite tendency, decreasing continually to a minimum (3.32 km hr-1) at a distance of 17 meters from the windbreaks before increasing once again. In addition, this system's net returns (Rs. 40,619) and benefit-cost ratio (0.61) were noticeably higher than those of open fields (Rs. 34,749 and benefit cost ration 0.52). In contrast to the control, the pH of the soil beneath the windbreak was reported to be considerably closer to neutral (7.46), while electrical conductivity (0.19 dS/m) was reduced. The impact of windbreaks was found to considerably increase soil organic carbon (0.68%), accessible nitrogen (234.46 kg/ha), phosphorus (75.75 kg/ha), and potassium (398.07 kg/ha) as compared to control. According to the study's overall findings, windbreak-protected paddy fields perform noticeably better than open ones.

Keywords: Windbreak, Casuarina, Paddy, Growth, Yield, Crop productivity, Soil Properties

Introduction :

Windbreaks are forms of agroforestry systems usually practiced for their protective function in arid, semi-arid, and coastal regions. It primarily aims at the reduction of wind speed and damage owing to the high-velocity winds, reduce soil erosion (Chang *et al*., 2021). Smith *et al.* (2021) consider windbreaks itself as a single system and alternately called hedgerows, shelterbelts, living snow fences, or vegetated environmental buffers based on specific purposes. Climate is the factor with the greatest impact on agricultural productivity. It is therefore not surprising that the practice of intentional microclimate modification is as old as the practice of agriculture itself. In particular, windbreaks providing shade and shelter have long been used as a tool to create a more benign and productive microclimate. Windbreaks have the potential to greatly increase animal, pasture, and agricultural output. Thus, planting tree windbreaks is seen to be a good approach to slow down land deterioration and potentially boost agricultural output. The main effect of a tree windbreak is to provide shelter – *i.e.*, a windbreak alters the mean wind speed, wind direction, and turbulence of the airflow (Cleugh 1998, Dhyani *et al.* 2016).

One of the main causes of the decline in rice quality and production is lodging. Plants that are unable to stand straight are said to be lodged, and this can result in a loss of production as the combine is unable to gather the grain from the plants. A large portion of the plant is destroyed by severe lodging, which lowers grain output, photosynthetic capacity, and harvesting efficiency. In addition to the direct impacts of wind and rain, an overabundance of soil nitrogen can also result in crop lodging (Lang *et al.* 2012). Casuarina windbreak trees, when planted on the edges of agricultural areas, have demonstrated significant potential in reducing wind speed and mitigating harm to cash crops. It is a multipurpose tree species amenable for agro and farm forestry system and also as windbreaks (Parthiban *et al.* 2014). Thus, the goal of the current study is to ascertain how casuarina windbreaks affect the economics and production of paddy crops. Therefore, the approach of this study focuses on the effects of windbreak on paddy crop this study developed an innovative framework to investigate the farmland growth and yield variation, soil fertility impact induced by the windbreak.

MATERIALS AND METHODS

Study area: The experiment was conducted during *kharif* season of 2020 and 2021 at PCP farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari, South Gujarat. Geographically it is located at 20.95° N latitude and 72.93° E longitude with an elevation of 11 m above mean sea level (AMSL). This area is typically characterized by humid and warm monsoon with rainfall of about 1500-1800 mm, moderately cold winter, and fairly hot and humid summer. The average annual temperature is 27.1 °C.

Methods: For the assessment of windbreaks effect on paddy, *Oryza sativa* (Variety: GNR-3) seedling was transplanted in line at 45 cm leeward side of *Casuarina equisetifolia* windbreak (15 years old single raw) and in open condition. This experiment was designed in a randomised block design with nine treatments (distance from windbreaks) viz., T_0:-At distance 2 m from wind break, T_1:- At distance 5 m from wind break, T_2:- At distance 8 m from wind break, T_3:- At distance 11 m from wind break, T_4:- At distance 14 m from wind break, T_5:- At distance 17 m from wind break, T_6:- At distance 20 m from wind break, T_7:- At distance 23 m from wind break and T_8:- without windbreaks field, and three replications. Required cultural operations carried out during the whole experiment. Wind velocity (km/hr) was measured at monthly interval in each treatments of distance from the windbreak by using digital wind anemometer. Essential observations of paddy were recorded as needed to fulfil the objectives. Treatment wise growth and yield data were collected from the experiment field. 2mx3m sample plot for each treatment (with three replications) was prepared. Before harvesting plant height (cm), number of tillers per plant and after harvesting total fresh wt. plant (kgha^{-1}), dry straw weight (kgha^{-1}) and grain weight (kgha^{-1}) were recorded.

Wind velocity measurement: An anemometer is an instrument used to measure the speed or velocity of wind. Using an anemometer, observations were made twice daily, in the morning and evening, during the paddy season.

Characters of windbreak: In present study the windbreak was single raw of 15 years old *Casuarina equisetifolia*. Its average height was 22 m and diameter 28 cm at breast height, Crown length 18 m and Crown width (North-South 6.3 m East-West 6.2 m).

Soil analysis: After the harvest of paddy soil samples were collected from 0 to 15 cm depth of all treated plot for soil physico-chemical properties analysis and analyzed in soil science laboratory, Department of natural resource management, College of Forestry, NAU, Navsari. Different standard methods were used for the pH (1:2.5) and electrical conductivity (EC) (1:2.5) of soils were measured using standard procedures as described by Jackson (1973). Organic carbon (OC) was determined using the Walkley Black method (1934). Available nitrogen (N) was estimated by modified alkaline permanganate method (Subbaiah and Asija, 1956). Available phosphorus (Olsen P) was measured using sodium bicarbonate (NaHCO3) as an extractant (Jackson, 1973). Available potassium (K) was determined using the ammonium acetate method (Jackson, 1973)

Statistical Analysis: Recorded two-year average data of variables were analysed and compared by analysis of variance (ANOVA) of randomised block design with the critical difference (CD, $p < 0.05$) (Panse and Sukhatme 1995).

RESULTS AND DISCUSSION

Effect of windbreaks on growth and yield

Growth and yield characteristics paddy are the most crucial factors to take into account when estimating crop production. The pooled analysis from the two years (2020 and 2021) of growth and yield variables are presented in Table 1. Results show that there was a significant effect of wind break (*Casuarina equisetifolia* L.) on productivity of paddy. Plant height (97.34 cm), number of tillers per plant (11.17), total fresh weight plant (17,799 kg ha^{-1}), dry straw weight (6,577 kg ha^{-1}) and grain yield (4,103 kg ha^{-1}) were significantly higher in the treatment T_5 (17 m far from windbreaks) due to the lower the wind velocity (3.32 km hr^{-1}) as compared to other treatments. Because of the wind breaks shade, treatment T_0 (2 m far from windbreaks) reported minimum plant height (83 cm), tillers per plant (8.17), total fresh weight plant (12,315 kg ha^{-1}), dry straw weight (4,855 kg ha^{-1}) and grain yield (3,101 kg ha^{-1}). However, results indicate that the increasing the distance from the windbreak increase the crop productivity. The wind speed is high near the windbreak the crop does not get much hindrance from the wind but as the wind speed decreases crop production increases further away from the windbreak. The higher the barrier, the higher the production

Kort (1988) provided support for this finding, revealing that windbreaks significantly enhance output for winter wheat (*Triticum aestivum*) by 23%, soybeans (*Glycine max*) by 15%, and maize (*Zea mays*) by 12%. Whereas soybeans responded to windbreaks in the most favorable way. Similarly, result was observed in plant fresh weight of rice was increased by sheltering (Monette and Stewart 1987). North side and narrow windbreaks compensated for the footprint of the windbreaks 71% of the time, while south side and wider windbreaks only compensated for the windbreaks footprint 38% of the time (Osorio *et al*. 2019). According to Liu *et al.* (2022), the environment competition between the shelterbelt and corn caused the corn yield to decrease close to it. However, after 1.2 H, the shelterbelt's effect on corn yield turned positive, growing steadily until it reached a maximum at 3.5 H before gradually declining. Similar results were also observed by Sirohi *et al*. (2022), Campi *et al*. (2009), Sudmeyer and Scott (2002).

Table 1: Effect of wind breaks (*Casuarina equisetifolia* L.) on crop productivity

Treatments	Plant height (cm)	Number of tiller per plant	Total fresh wt. plant ($kgha^{-1}$)	Dry straw weight ($kgha^{-1}$)	Grain weight ($kgha^{-1}$)
T_0 (2 m)	83.00	8.17	12,315	4,855	3,101
T_1 (5 m)	85.00	8.67	14,450	5,101	3,804
T_2 (8 m)	88.17	9.50	14,564	5,096	3,916

T_3 (11 m)	90.17	9.67	15,188	5,434	4,024
T_4 (14 m)	95.50	10.50	17,143	6,021	4,069
T_5 (17 m)	97.34	11.17	17,799	6,577	4,103
T_6 (20 m)	89.17	10.00	15,754	5,897	4,003
T_7 (23 m)	84.17	8.50	13,725	4,818	3,498
T_8 (Control)	89.17	9.00	15,170	5,230	4,024
SEM (±)	3.184	0.317	444.47	280.68	244.19
CD @ 5%	9.54	0.912	1332.14	841.23	731.86
CV%	6.19	5.80	5.09	8.92	11.02

Effect of windbreaks on economic

Estimated the economics of the systems reported highest net returns Rs. 40,619 and benefit cost ration 0.61 were generated from treatment T_5 (At distance 17 m from wind break) as compared to other treatments. Whereas, treatment T_8 Without windbreaks (open field) has net returns Rs. 34,749 and benefit cost ration 0.52 (Table 2). As the tree row acts as a windbreak, the crop gets a barrier from the wind speed and the crop growth is improved and the crop does not lodged so the yield is good.

Several studied were supported by different researches. Brandle *et al*. (1984) studied field windbreaks systems that occupy between 5 and 6% of the crop field provide positive economic returns to producers based entirely on the increased yields found in sheltered areas. An interactive computer model was created by Brandle and Kort (1991) to assess the financial benefits to grain growers who provide windbreak protection for their crops.Grala and Colletti (2003) Fast-growing, long-lasting windbreaks were more advantageous economically. They stressed that investing in a windbreak system is a long-term commitment. Helmers and Brandle (2005) they compared to the net return for unprotected maize and soybean, an ideal spacing of 13 H enhanced net returns by 7.6% for corn and 9.2% for soybeans on the windbreaks investment.

Table 2: Gross return, Net return and BCR

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)	Cost of cultivation	Gross Realization (Rs./ha)	Net Realization (Rs./ha)	BCR
T_0 (2 m)	3,101	4,055	66,716	79,314	12,598	0.19
T_1 (5 m)	3,804	4,801	66,716	96,688	29,972	0.45
T_2 (8 m)	4,016	4,895	66,716	1,01,469	34,753	0.52
T_3 (11 m)	4,082	4,934	66,716	1,02,991	36,275	0.54
T_4 (14 m)	4,143	4,921	66,716	1,04,227	37,511	0.56
T_5 (17 m)	4,315	4,777	66,716	1,07,335	40,619	0.61
T_6 (20 m)	4,003	4,997	66,716	1,01,553	34,837	0.52
T_7 (23 m)	3,513	4,917	66,716	90,983	24,267	0.36

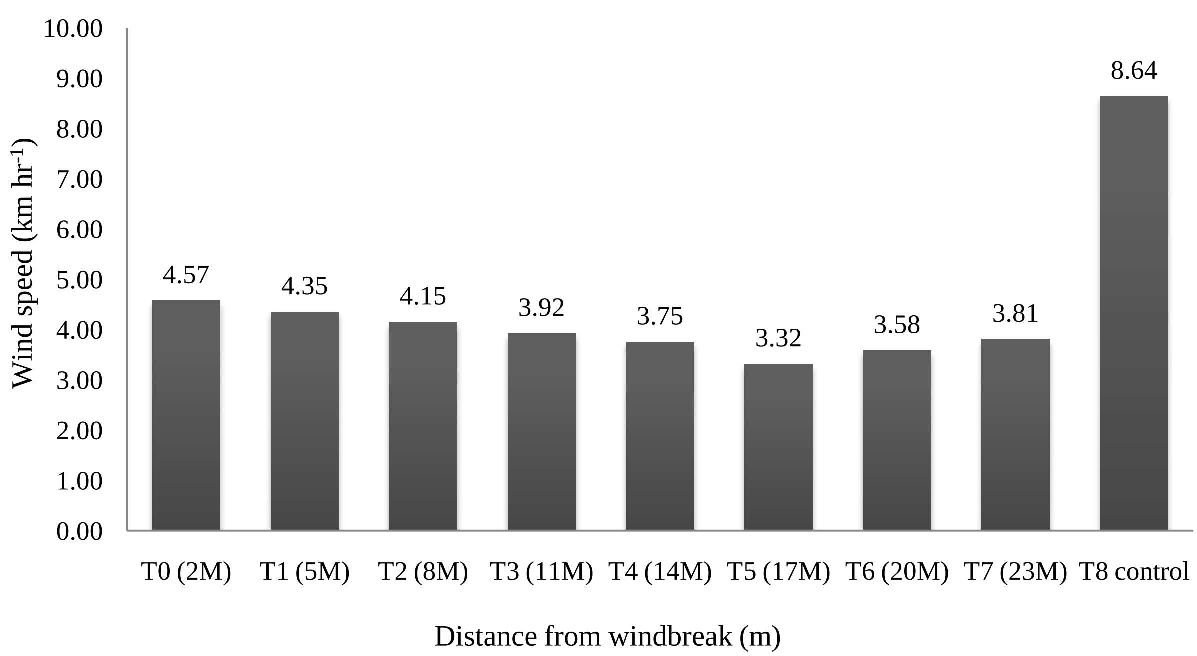
T_8 (Control)	3,960	5,230	66,716	1,01,465	34,749	0.52

Note: Straw rate @ Rs. 3.5 kg^{-1} and Grain rate @ Rs. 21kg^{-1}

Effect of windbreaks on wind velocity (km hr^{-1})

Every month, the anemometer was used to measure the wind speed. Figure 1 shows average statistics on how various treatments affect wind velocity visually. Results are indicating that wind speed significantly affected due to the different treatments. Observed data showed that among the different treatments, significantly higher wind velocity (8.64 km hr^{-1}) recorded in open treatment (without windbreak) as compared leeward side of windbreak. In leeward side of windbreak, from the base of windbreak to increase the distance 2 m (T_0) to 17 m (T_5) wind velocity continuously decrease, T_5 (17 m) shows minimum wind velocity (3.32 km hr^{-1}) after that continually increased wind velocity. When wind encounters a porous obstacle, such as a windbreak or shelterbelt, air pressure increases on the windward side and decreases on the leeward side. As a result, the airstream approaching the barrier is interrupted, and a portion of it moves over the barrier, resulting in a jet of higher wind speed. The remainder of the airstream then moves through the barrier to its edge downstream, pushed along by the decrease in pressure across the shelterbelt's width; as it emerges again, that airstream is interrupted further as its air pressure adjusts to the surrounding area. This results in slower windspeed further downwind, reaching a minimum at a distance of about 3 to 5 times the windbreak's height. Similar result found by Foereid *et al*. (2002) that wind speed was reduced; the ratio *u*/*u*0 was found to be 0.37 at the point closest to the windbreaks. At 35m from the windbreaks *u*/*u*0 reached 0.86 and did not increase further. This seems to indicate that the equipment measured significantly lower values than the reference; in particular, it had a higher 0-threshold. The same study also supported by (Mulheran and Bradley 1977, Brenner *et al*. 1995, Zhang *et al.* 1995, McNaugthon1988).

Figure 1: Effect of wind breaks (*Casuarina equisetifolia* L.) on wind velocity (km hr^{-1})



Effect of windbreaks on soil physico-chemical properties

Soil fertility is a major factor in crop development and yield. Numerous elements, including organic matter, fertilizer, climate, and location, affect soil fertility. A windbreak can enrich the soil with organic matter from the roots of nearby trees. In present study the effect of windbreak on soil properties were analyzed and presented in Table 3. Presented data revealed that the different distances from windbreak significantly affect the soil properties. The experimental results were indicating that pH of soil was found significantly near neutral range as compare to control (7.73). Soil EC 1:2.5 (dSm^{-1}) showed that under effect of windbreaks EC was decreased in compare to control (0.34). Whereas, the soil fertility parameters soil organic carbon (0.68 %), available nitrogen (234.46 kg ha^{-1}), phosphorous (75.75 kg ha^{-1}) and potash (398.07 kg ha^{-1}) were recorded significantly higher in T_0 treatment (2 m from windbreak) as compared to others treatments. Whereas lowest recorded in control (T_8). The results indicate that the increasing the distance from the windbreak decreased the soil physio-chemical properties. Same study carried out by Lalozaei *et al.* (2016) that with the construction of the two windbreaks, electro conductivity, organic matter, calcium, potassium, sodium and carbon to nitrogen ratio had a significant (95%) increase compared to the control region. Chauhan *et al.* 2010 reported that after 6 years of poplar planting, organic carbon increased in soil than pure wheat crop. Sirohi *et al.* (2022) carried out that the highest available soil N (365.2 kg ha^{-1}), P (19.7 kg ha^{-1}) and K (357.3 kg ha^{-1}) were recorded near the tree line at a distance of 2 m. Similar study carried out by (Shah and Kalra 1970, Chang *et al*. 2021).

Table 3:Effect of windbreaks on soil physio-chemical properties of paddy field

Treatments	Soil pH	Soil EC (dS/m)	Soil OC (%)	Soil Available Nitrogen (kg/ha)	Soil Available Phosphorous (kg/ha)	Soil Available Potash (kg/ha)
T_0 (2 m)	7.46	0.19	0.68	234.46	75.75	398.07
T_1 (5 m)	7.37	0.26	0.56	230.54	72.35	370.13
T_2 (8 m)	7.52	0.27	0.53	229.50	71.44	349.75
T_3 (11 m)	7.66	0.27	0.50	226.22	69.55	344.82
T_4 (14 m)	7.68	0.28	0.49	225.00	68.82	340.15
T_5 (17 m)	7.68	0.28	0.48	224.12	68.55	339.17
T_6 (20 m)	7.69	0.29	0.48	223.30	67.52	339.05
T_7 (23 m)	7.69	0.30	0.47	220.54	66.96	336.12
T_8 (Control)	7.73	0.34	0.48	211.45	58.70	322.27
SEM (±)	0.026	0.013	0.019	5.581	6.749	10.24
CD @ 5%	0.08	0.04	0.06	16.72	18.97	30.725
CV %	0.60	8.57	6.43	4.30	17.29	5.08

CONCLUSION

Based on the above discussion, it can be concluded that the experiment demonstrated the considerable effects of windbreaks at varying distances from the windbreak on paddy growth and yield. The impact of windbreaks is evident at a distance of 17 meters from them, as evidenced by the notable increase in straw height, the number of tillers per plant, the total weight of fresh plants, dry straw weight of paddy, and dry grain weight of rice. Beyond that point, however, growth and paddy production begin to decline. It is evident that from 2 to 17 meters from the wind break, the wind velocity dramatically decreased before beginning to increase. In addition to improving the qualities of the soil, windbreaks have a significant effect on soil health.

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