Characterization of Wind Profile over Wheat and Mustard Canopies under Sole and Intercropped Conditions in Lower Gangetic Plain of Eastern India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SJ carried out the experiment, wrote the protocol and wrote the first draft of the manuscript. Authors PKC and RN managed the analyses of the study, preparation of final manuscript. Authors PB, RN and PKC supervised the experiment and helped in final manuscript preparation. All authors read and approved the final manuscript.

ABSTRACT

Aim: Wind profile over a crop canopy affects several physiological processes. The nature of the wind profile above the crop canopy of a single crop has been reported in the literature. However, under intercropping system, the nature of wind profile isn’t well discussed.

Methodology: With this background, a two-year experiment was conducted with five different crop combinations (T1- sole wheat, T2- sole mustard, T3- two wheat: six mustard, T4- four wheat: four mustard and T5- six wheat: two mustard) in Randomized Block Design (RBD) of 54 m\textsuperscript{2} plot size.
Wind speed was measured at 0.5, 1.0 and 1.5 m above the crop canopy from 9:30 to 13:30 hour at two-hour interval. The observations were taken from 30 to 80 days after emergence (DAE) at weekly interval.

**Results:** Results showed that the wind speed gradually increased with the increment of height over the sole wheat. Wind speed sharply declined under intercropping over the wheat canopy. The percentage reduction in T3 was maximal on 58 DAE. The wind speed gradually increased with height for all observations in mustard irrespective of treatment combinations. However, under intercropping, wind speed reduced marginally at 0.5 m above mustard height compared to the sole mustard.

**Conclusion:** Reduced wind speed over wheat canopy causes reduction of mass and momentum transfer thus reducing the carbon exchange rate which might be one of the reasons for lower biomass production in wheat-mustard intercrop in comparison to sole wheat crop.

**Keywords:** Anemometer; intercropping system; mustard; sole crop; wheat; wind profile.

### 1. INTRODUCTION

A combination of two or more crops where grown together on same piece of land during a growing season is termed as intercropping [1]. Intercropping is considered as a traditional system of cultivation where a predominant crop of the area is cultivated with other crops as per requirement [2]. In India different types of crops are used under intercropping system. Intercropping system in Lower Gangetic Plains (LGP) of West Bengal (Eastern India) adopted mainly in pre – monsoon and post – monsoon seasons, where a variety of crops like sesame – green gram, wheat – mustard, wheat – lentil, maize – cowpea, etc. are grown in different combinations. Intercropping is practised for utilizing the resources in an improved manner. It was observed that higher use of resources and higher radiation use efficiency under pearl millet and groundnut intercropping [3]. Resources in intercropping are comparatively less than monoculture due to complexities in interspecies interaction [4]. Discontinuous canopy profile with different growth habits under intercropping affects radiation capture, particularly radiation use efficiency [5], wind flow over the crop. There is need to enhance agricultural research on intercropping systems on different aspects [6]. Wind profile study over a crop canopy is needed for understanding the lodging characteristics of a particular species [7]. The extent of lodging depend on plant height, strength of the stem, plant morphology, chemical composition of the stem, plant population per unit area as well as developmental phase of the crop plant [8-16]. Under intercropping system lodging character is more important than sole crop system because of increment of mustard shading by lodged of the accompanying crop. Therefore, research on wind profile under intercropping is of immense importance to delineate the environmental impact on crop compared to monoculture. The nature and shape of wind profile above crop surface depends on a number of crop factors viz. height, leaf size, volume etc. at the crop surface. Heat and mass transfer are sustained by molecular diffusion through a thin layer of air known as boundary layer. The behaviour of this layer depends on the viscous properties of air and on the transfer of momentum associated with viscous forces [17]. The exchange of mass and momentum between the crop surface and surrounding air depends on the nature of the crop. The interaction of the crop with its surrounding air differs in monocropping and multiple cropping. The literature is available in case of sole crop [18-20]. The information on intercropping is scanty. Because most of the aerodynamic studies were conducted over sole crops [21-23]. With this background, the present experiment has been planned to elucidate the impact of intercropping system on wind profile over the system. Two dominant crops of winter season had been selected for this purpose.

### 2. MATERIALS AND METHODS

#### 2.1 Experimental Site

The field experiment was carried out at Students’ Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya (Lat 22°58´N, Long 88°31´E), West Bengal, India. The study site is flat, under Lower Gangetic Plain (LGP), located at an altitude of 9.75 m above mean sea level.

#### 2.2 Experimental Soil

The experimental soil is under the order of Entisol and the great group is under Fluvaquets. The texture of soil was sandy loam with
good drainage capacity. The soil comprises of 74.2% sand, 14.2% silt and 11.5% clay and the bulk density of 0.45 – 0.60 m layer soil depth is 1.4 g cc⁻¹. The pH of the soil is 6.7. The soil contains 0.54% organic carbon, 0.053% total nitrogen, 15 kg ha⁻¹ available phosphorous and 153.5 kg ha⁻¹ available potassium.

2.3 Agronomic Practices

The land was cultivated first by heavy ploughing through tractor and then it was prepared by two crosses-wise pass with a rotary power tiller to have a good tilth. All weeds were removed by hand weeding and subsequently the land surface was levelled by an indigenous leveller. Fertilizers were applied just before sowing of seeds and mixed with the soil. Fertilizer application to the sole crop plots of both the component crops (wheat and mustard) was done based on recommendation of wheat (120:60:40 for N-P-K Kg) and mustard crop (60:40:40 for N-P-K Kg). For intercrop treatments, fertilizers were applied on the basis of area occupied by each component crop in the respective plots with similar recommended dose mentioned above. One third of the recommended N, full of P₂O₅ and K₂O were applied as basal; 1/3rd of N was applied as top dressing just before first irrigation i.e 25 days after sowing (DAS) and the remaining 1/3rd was applied before second irrigation i.e. 45 days after emergence (DAE). Nitrogen was split into 120 kg and 3 kg ha⁻¹ respectively. One pre – sowing irrigation of 3 cm was given followed by irrigation as and when required based the physiological stages of wheat crop. The sole mustard crop was given 3 cm irrigation at 75% flowering besides a pre – sowing irrigation. Wheat crop was given total five irrigations 3 cm each including pre – sowing one. No insecticide or fungicide was applied for controlling pest and diseases. For wheat, the variety PBW – 343 (125 – 130 days duration) and for mustard, B – 85 (100 days duration) were used.

2.4 Design and Layout

The experiment was laid out in simple randomized block design (RBD) with five treatments and six replications. The plot size was 50 m² (5 m×10m). The row to row and plant to plant spacing were 30 cm and 10 cm respectively for each component crop.

2.5 Treatment Combinations

The treatment details of the experiment were as follows;

- T1: sole wheat
- T2: sole mustard
- T3: two rows of wheat were alternated with six rows of mustard (2W:6M).
- T4: four rows of wheat alternated with four rows of mustard (4W:4M).
- T5: six rows of wheat alternated with two rows of mustard (6W:2M).

2.6 Instrumentation

There was 100 m open space around the experimental area and the wind had a free flow. One wooden mast of 5 m height with fittings at different levels were placed in the middle of the wheat and mustard rows all together 8 masts were used for 5 treatment combinations – 2 for 2 sole crop plots and 6 for 3 intercrop treatments. Micro anemometers (Model OC Anemo – 01) were placed at 0.5, 1.0 and 1.5 m above the crop canopy. Cup type anemometer is used as sensor. Sensing was done by optical sensor and chopper wheel. The starting threshold of the anemometer was less than 0.3 ms⁻¹, range is 0 - 60 ms⁻¹. The radius of the cup was 0.025 m, radius of the assembly was 0.11 m and the height was 0.16 m. The cup was made of stainless steel. Wind speed was recorded at 9:30, 11:30 and 13:30 hour above the specified heights of the canopy. When mustard crop attain the maturity. For wind speed observation, each anemometer was allowed to run for 15 minutes and data were collected with the help of data – logger (Model: FDBMKIV). The outliers of each observation were discarded and to achieve homogeneity of wind speed and an average was taken. As wind speed data was a single time point data and were not replicated, it was not subjected to statistical analysis. Detail position of anemometers with wooden mast within the treatment plots have been shown in Plate 1. The schematic diagram of wooden mast with the anemometer orientation is given in Fig. 1. The relationship between anemometer height and wind speed at 11:30 hour was computed because lower number of outliers in wind speed data was observed as compared to wind speed data obtained at 9:30 or 13:30 hour.
2.7 Wind Speed during Experimental Period

The experimental site falls under tropical humid climate. The present experiment was carried out during November to February in 2008–2009 and 2009–2010. The experimental period spanned in between 44 to 52 and 1 to 8 standard meteorological week (SMW). The daily wind speed data was collected from the adjacent Agrometeorological Observatory. The mean wind speed on SMW basis is given in Table 1. During early stage of growth, the crops were exposed to lower wind speed than the normal values (up to 52nd SMW) in both the years. However, during the later period, crops experienced higher wind speed (1st to 3rd SMW) particularly in the second year.

![Fig. 1. Schematic diagram of arrangements of anemometers on the wooden mast, the height of the anemometer can be changed as per crop height]

3. RESULTS AND DISCUSSION

The diurnal variation in wind speed over sole and intercropped wheat is presented in Table 2. The wind speed at all levels was higher in sole and T5 treatment, where the number of wheat rows was more as compared to the T3 and T4 treatments. This observation was noted irrespective of the growth phases and the time of observation. The minimum wind speed at all levels was observed in T3 treatment, where only two wheat rows were alternated with six mustard rows. On 30th DAE at 11:30 h in the first-year experiment, wind speed reduced by 20, 62.5 and 44.4% respectively at 50, 100 and 150 cm above crop height. In the second-year experiment, the magnitude of reductions was 40, 22.2 and 30.8% respectively at the specified heights. In T4 treatment, there was no reduction of wind speed at 50 cm and 150 cm above crop height in the first year; whereas in the second-year, the reductions were 20, 11.1 and 23.1% respectively at 50, 100 and 150 cm above crop height. The results showed that the wind speed drastically reduced over the wheat canopy because of lower number of wheat rows as compared to mustard. Among the three intercropping treatments, mean percentage reductions in wind speed at all the levels gradually decreased with the reduction in the number of mustard rows in the system. In T3 treatment the reduction was highest. During the later phase of growth (58 DAE onwards), the wind speed at all heights increased in all the treatment combinations irrespective of year and time of observations. The wind speed over intercropped wheat, recorded a reduction because of the associated taller mustard crop. The lowest wind speed observed at the 50 cm above crop height was due to the increased drag by wheat leaf. Under intercropping, the mustard had larger leaf size than the wheat crop. It was reported that large leaf creates higher drag, which reduces the wind speed over the wheat canopy [24]. In case of mustard, wind speed increased gradually with the increment anemometer height irrespective of time and year of observations. There was no variation in wind speed over mustard canopy under intercropping because there was no interference by the wheat canopy due to its shorter height (Table 3).

The changes in wind speed with the increment of anemometer height above the sole wheat and mustard and intercropped wheat at 11:30 h followed logarithmic increment (Fig. 2). R2 value increased with the increment of the number of wheat rows under intercropping situation indication closer association. The wind profile above the crop is influenced by leaf area index and the plant height significantly in sole crop [20]. In the present experiment, the wind speed over wheat declined drastically when the wheat rows were lowest in number (T3). This low wind speed over the wheat canopy may lead to lower yield because of slow exchange process [25]. The increase in the wind speed over the mustard canopy might be beneficial because of higher transpiration rate, lower diffusion resistance and lower leaf temperature, which helped in biomass accumulation [26,27]. The present study indicated the role of an important environment parameter that is wind speed explaining the lower yield of short height crop under intercropping system.
Plate 1. Wheat and mustard crop under sole and intercropped situation with position of the wooden mast and anemometer
Table 1. Normal and observed wind speed (WS) during the experimental period

| SMW | Normal WS (ms$^{-1}$) | Observed WS (ms$^{-1}$) |
|-----|-----------------------|-------------------------|
|     |                       | 2008 - 09 | 2009 - 10 |
| 44  | 0.53                  | 0.30 | 0.15 |
| 45  | 0.67                  | 0.12 | 0.12 |
| 46  | 0.64                  | 0.14 | 0.00 |
| 47  | 0.70                  | 0.20 | 0.04 |
| 48  | 0.61                  | 0.13 | 0.22 |
| 49  | 0.64                  | 0.09 | 0.08 |
| 50  | 0.75                  | 0.10 | 0.12 |
| 51  | 0.72                  | 0.26 | 0.19 |
| 52  | 0.70                  | 0.22 | 0.23 |
| 1   | 0.72                  | 0.18 | 2.03 |
| 2   | 0.83                  | 0.33 | 1.97 |
| 3   | 0.78                  | 0.28 | 1.03 |
| 4   | 0.78                  | 0.40 | 0.25 |
| 5   | 0.89                  | 0.44 | 0.29 |
| 6   | 0.83                  | 0.34 | 0.09 |
| 7   | 0.78                  | 0.33 | 0.09 |
| 8   | 1.03                  | 0.17 | 0.15 |

[SMW = Standard Meteorological Week]

Fig. 2. Relationship between anemometer height and wind speed at 11:30 h under different treatments
## Table 2. Diurnal variation in wind speed (m/sec) over sole and intercropped wheat under wheat-mustard intercropping system

| Treatment | h   | 30 DAE | 09:30-11:30 | 11:30-13:30 | 13:30-15:30 | 15:30-17:30 | 17:30-19:30 | 19:30-21:30 | 21:30-23:30 | 23:30-01:30 | 01:30-03:30 | 03:30-05:30 | 05:30-07:30 | 07:30-09:30 |
|-----------|-----|--------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| T1        | 1st | 0.6    | 0.5         | 0.2         | 0.4         | 0.5         | 0.6         | 0.8         | 0.9         | 0.4         | 0.7         | 1.1         | 0.8         | 1.7         |
|           | 2nd | 0.8    | 1.6         | 0.4         | 0.7         | 0.9         | 1.1         | 0.3         | 0.4         | 0.8         | 1.2         | 0.5         | 0.9         | 1.5         |
|           | 3rd | 1.3    | 1.8         | 0.8         | 0.9         | 1.3         | 1.5         | 0.6         | 0.8         | 1.9         | 0.9         | 1.7         | 1.9         | 0.6         |
| T3        | 1st | 0.2    | 0.4         | 0.1         | 0.2         | 0.3         | 0.3         | 0.05        | 0.1         | 0.3         | 0.4         | 0.5         | 0.1         | 0.2         |
|           | 2nd | 0.6    | 0.6         | 0.3         | 0.5         | 0.7         | 0.5         | 0.1         | 0.2         | 0.5         | 0.5         | 0.7         | 0.2         | 0.3         |
|           | 3rd | 0.8    | 1.1         | 0.6         | 0.7         | 0.9         | 0.9         | 0.3         | 0.4         | 0.8         | 0.6         | 0.9         | 1.1         | 0.4         |
| T4        | 1st | 0.4    | 0.5         | 0.2         | 0.3         | 0.4         | 0.5         | 0.1         | 0.2         | 0.5         | 0.4         | 0.6         | 0.2         | 0.5         |
|           | 2nd | 0.7    | 1.1         | 0.4         | 0.6         | 0.8         | 0.7         | 0.2         | 0.3         | 0.7         | 0.7         | 0.8         | 0.5         | 0.8         |
|           | 3rd | 1.1    | 1.6         | 0.8         | 0.8         | 1.3         | 1.3         | 0.5         | 0.6         | 0.9         | 1.1         | 1.3         | 0.7         | 1.1         |
| T5        | 1st | 0.6    | 0.5         | 0.2         | 0.4         | 0.5         | 0.6         | 0.1         | 0.2         | 0.6         | 0.6         | 0.7         | 0.9         | 0.3         |
|           | 2nd | 0.8    | 1.2         | 0.4         | 0.7         | 0.9         | 1.3         | 0.3         | 0.4         | 0.8         | 0.8         | 0.9         | 1.2         | 0.7         |
|           | 3rd | 1.2    | 1.7         | 0.8         | 0.9         | 1.1         | 1.4         | 0.6         | 0.8         | 1.9         | 1.3         | 1.5         | 0.8         | 1.2         |

Jena et al.; CJAST, 39(42): 94-104, 2020; Article no. CJAST.64070

[height of anemometer, 1st=50cm above crop height, 2nd=700cm above crop height, 3rd=150cm above crop height]
### Table 3. Diurnal variation in wind speed (m/sec) over sole and intercropped mustard under wheat-mustard intercropping system

| Treatment | h | 30 DAE | 37 DAE | 44 DAE | 51 DAE |
|-----------|---|--------|--------|--------|--------|
|           |   | 2008-09 | 2009-10 | 2008-09 | 2009-10 | 2008-09 | 2009-10 | 2008-09 | 2009-10 | 2008-09 | 2009-10 | 2008-09 | 2009-10 | 2008-09 | 2009-10 | 2008-09 | 2009-10 |
|           |   | 9:30 | 11:30 | 13:30 | 9:30 | 11:30 | 13:30 | 9:30 | 11:30 | 13:30 | 9:30 | 11:30 | 13:30 | 9:30 | 11:30 | 13:30 | 9:30 | 11:30 | 13:30 |
| T<sub>2</sub> | 1<sup>st</sup> | 0.8 | 0.8 | 0.4 | 0.4 | 0.9 | 0.3 | 0.8 | 0.7 | 0.8 | 1 | 1.5 | 0.5 | 1.2 | 1.4 | 1 | 1.2 | 1.9 | 0.8 | 0.9 | 1.8 | 0.9 | 1.1 | 1.3 |
|           | 2<sup>nd</sup> | 1 | 1.9 | 0.6 | 1 | 1.6 | 1.2 | 0.5 | 0.8 | 0.9 | 1.1 | 1.5 | 1.8 | 0.8 | 1.5 | 2.4 | 1.5 | 1.5 | 2.4 | 0.9 | 1.1 | 1.9 | 1.5 | 1.7 |
|           | 3<sup>rd</sup> | 1.5 | 2.1 | 0.9 | 1.5 | 1.8 | 1.6 | 0.8 | 0.7 | 0.8 | 1 | 1.5 | 0.5 | 1.2 | 1.4 | 1 | 1.2 | 1.9 | 0.6 | 0.9 | 1.6 | 0.9 | 1.1 | 1.3 |
| T<sub>3</sub> | 1<sup>st</sup> | 0.8 | 0.8 | 0.4 | 0.4 | 0.9 | 0.8 | 0.3 | 0.6 | 0.7 | 0.8 | 1 | 1.5 | 0.5 | 1.2 | 1.4 | 1 | 1.2 | 1.9 | 0.6 | 0.9 | 1.6 | 0.9 | 1.1 | 1.3 |
|           | 2<sup>nd</sup> | 1 | 1.9 | 0.6 | 1 | 1.6 | 1.2 | 0.5 | 0.8 | 0.9 | 1.1 | 1.5 | 1.8 | 0.8 | 1.5 | 2.4 | 1.5 | 1.5 | 2.4 | 0.9 | 1.1 | 1.9 | 1.5 | 1.7 |
|           | 3<sup>rd</sup> | 1.5 | 2.1 | 0.9 | 1.5 | 1.8 | 1.6 | 0.8 | 1 | 1.1 | 1.5 | 1.9 | 2.6 | 1 | 1.6 | 2.5 | 1.8 | 1.9 | 2.7 | 1.2 | 1.2 | 2.2 | 1.5 | 1.9 | 2.1 |
| T<sub>4</sub> | 1<sup>st</sup> | 0.8 | 0.8 | 0.4 | 0.4 | 0.9 | 0.8 | 0.3 | 0.6 | 0.7 | 0.8 | 1 | 1.5 | 0.5 | 1.2 | 1.4 | 1 | 1.2 | 1.9 | 0.6 | 0.9 | 1.6 | 0.9 | 1.1 | 1.3 |
|           | 2<sup>nd</sup> | 1 | 1.9 | 0.6 | 1 | 1.6 | 1.2 | 0.5 | 0.8 | 0.9 | 1.1 | 1.5 | 1.8 | 0.8 | 1.5 | 2.4 | 1.5 | 1.5 | 2.4 | 0.9 | 1.1 | 1.9 | 1.5 | 1.7 |
|           | 3<sup>rd</sup> | 1.5 | 2.1 | 0.9 | 1.5 | 1.8 | 1.6 | 0.8 | 1 | 1.1 | 1.5 | 1.9 | 2.6 | 1 | 1.6 | 2.5 | 1.8 | 1.9 | 2.7 | 1.2 | 1.2 | 2.2 | 1.5 | 1.9 | 2.1 |
| T<sub>5</sub> | 1<sup>st</sup> | 0.8 | 0.8 | 0.4 | 0.4 | 0.9 | 0.8 | 0.3 | 0.6 | 0.7 | 0.8 | 1 | 1.5 | 0.5 | 1.2 | 1.4 | 1 | 1.2 | 1.9 | 0.6 | 0.9 | 1.6 | 0.9 | 1.1 | 1.3 |
|           | 2<sup>nd</sup> | 1 | 1.9 | 0.6 | 1 | 1.6 | 1.2 | 0.5 | 0.8 | 0.9 | 1.1 | 1.5 | 1.8 | 0.8 | 1.5 | 2.4 | 1.5 | 1.5 | 2.4 | 0.9 | 1.1 | 1.9 | 1.5 | 1.7 |
|           | 3<sup>rd</sup> | 1.5 | 2.1 | 0.9 | 1.5 | 1.8 | 1.6 | 0.8 | 1 | 1.1 | 1.5 | 1.9 | 2.6 | 1 | 1.6 | 2.5 | 1.8 | 1.9 | 2.7 | 1.2 | 1.2 | 2.2 | 1.5 | 1.9 | 2.1 |

| *h=Height of anemometer, *1=30cm above crop height, *2=100cm above crop height, *3=150cm above crop height|

Jena et al.: CJAST, 39(42): 94-104, 2020; Article no. CJAST.64070
4. CONCLUSION

Under intercropping, wind speed over wheat canopy was reduced due to differential drag forces existed on different types of canopy. Reductions in wind speed over the wheat canopy reduced the rate of mass and momentum transfer thus reducing the carbon exchange rate which might be one of the probable reasons for lower biomass development in wheat in comparison to sole wheat. On the other hand, the wind speed over the mustard canopy was not disturbed because of the low height of wheat crop. On the basis of wind profile analysis over the sole and intercrop, 4:4 wheat – mustard intercropping system may be recommended for better productivity of both the crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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