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Interception and Use of Solar Radiation in Mustard/ Grass Pea Intercropping

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Authors' contributions

This work was carried out in collaboration between all authors. Author MSR conducted field experiment and wrote the manuscript. Author MAA designed the study and analyzed data set. Author IJS managed literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Solar radiation is of prime importance as it drives primary growth processes of plants. However its use in mustard and grass pea association is not yet analyzed. Therefore, a study was conducted at the Bangladesh Agricultural University during the cropping season extended from November 2014 to March 2015 to assess whether the mustard and grass pea crops are compatible when they grow together as intercrops in terms of radiation interception and use along with growth and productivity performances. Mustard was considered as a dominate crop and grass pea as an intercrop. The experiment comprised four treatments viz. sole mustard, sole grass pea, single row alternate intercropping (i.e. 1M:1G, where one row of mustard was grown followed by one row of grass pea), and double grass pea row intercropping (i.e. 1M:2G, where one row of mustard followed by two rows of grass pea). Both mustard and grass pea plants in sole cropping had higher leaf area index (LAI) and total dry matter (TDM) accumulation as compared to that at intercropping. Mustard grown with 1M:1G intercropping system showed higher LAI and TDM accumulation than those at the 1M:2G system however, opposite trend was found for grass pea. The combine intercrop canopy of 1M:2G showed higher radiation-use efficiency (RUE; 2.44 g MJ^{-1} PAR) followed by 1M:1G (2.29 g MJ^{-1} PAR) and sole mustard canopies (1.89 g MJ^{-1} PAR) whereas the sole grass pea stands

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showed minimum RUE (1.17 g MJ^{-1} PAR). Maximum grain yield of mustard (2.32 t ha^{-1}) was harvested from sole cropping which was about 19 and 31% higher than that obtained from 1M:1G (1.87 t ha^{-1}) and 1M:2G (1.60 t ha^{-1}) intercropped mustard, respectively. Similarly, sole grass pea (1.45 t ha^{-1}) produced about 32 and 3% higher seed yield as compared to single (0.99 t ha^{-1}) and double row (1.41 t ha^{-1}) intercropped grass pea, respectively. The 1M:1G and 1M:2G combined intercropping systems gave the highest land equivalent ratio (1.493 and 1.663) and area time equivalent ratio (1.313 and 1.507, respectively). In 1M:1G intercropping system, mustard exhibited higher competitive ratio over grass pea but in 1M:2G intercropping system grass pea significantly dominated over mustard. It can be concluded that the mustard and grass pea crops are compatible in their intercropping mixture and the performance of double row of grass pea alternatively grown with a single row of mustard is superior to their sole stands or single row intercropping system due to the improved utilization of solar radiation.

Keywords: Grass pea; light interception; mustard; pure crop; radiation-use efficiency.

1. INTRODUCTION

Mustard (*Brassica spp.*) and grass pea (*Lathyrus sativus* L.) – two important winter crops of Bangladesh. Socioeconomically these crops are very important as their versatile use to all types of people of the country. These crops are also unique for their wider adaptability along with requirement of minimum inputs to give reasonable yield. However, availability of land is quite critical in the country that limits the cultivation of these crops. Therefore, intercropping practice could provide a better avenue to cultivate mustard and grass pea in the same piece of land as the practice is proven as a sustainable cultivation technique in many countries of the world where expansion of land is not possible for over increasing food demands of growing population. Intercropping is also considered as a well recognized practice for better land use along with substantial yield advantages as compared to sole cropping [1-4].

Intercropping with legume species is beneficial as it helps to improve the soil fertility in addition to the increase the plant productivity. Generally legumes in association with non-legumes not only help to utilize the nitrogen being fixed in the current growing season but also keep residual nutrients in soil [5]. Therefore, suitable combination of crop species is very important for successful intercrop productivity [6-8]. Mustard-grass pea mixed cropping may give higher production as well better cash returns per unit of land as compared to their pure cultures; however the association is not yet evaluated.

The arrangement, shape and number of leaves in plant canopy affect the penetration, interception, distribution and reflection of light [9]). Larger interception of light in crop canopy with smaller mutual shading produces higher harvest index [10,11]. Absorption of light by different row crops depends on row width, width of inter-row, row height and sun and row's geometry [12]. Dry matter production is a function of the total light energy intercepted, which drives photosynthesis and is the total amount of CO_2 assimilated minus losses by respiration [11]. On the other hand crop biomass production and yield are reduced with reducing radiation interception and use [13-16]. However, no research regarding the underlying concept on the mustard/grass pea intercrop association is tested. Therefore, the present study was undertaken to evaluate the radiation interception and use along with the growth and productivity of mustard and grass pea when they grown alone as pure crops and in mixture.

2. MATERIALS AND METHODS

2.1 Site, Crop Husbandry and Experimentation

The experiment was conducted in the Crop Botany Field Laboratory (at 24º25″ N latitude and 90º50″ E longitude at 18 m above the sea level.), Bangladesh Agricultural University, Mymensingh during the cropping season extended from November 2014 to March 2015. The field is medium high land belonging to the Sonatola soil series of grey flood plain soil under the Agro-Ecological Zone-9 (AEZ-9) of Old Brahmaputra Flood Plain. The soil is silt loam with imperfectly to poorly drained permeability. There was a moderate cold air from November to early February and high temperature during the rest of the year. The site is characterized with minimum rainfall along with dry climate during November to April and enough rainfall with moist climate during the remaining period of the year.

The mean temperature, relative humidity, solar intensity and sun duration in the experimental site from November 2014 to March 2015 were found as 21.6 (±3.1)ºC and 81 (±7)%, 286 (±93) W m^{-2} and 5.32 (±2.85) hour, respectively (Fig. 1). The experiment was conducted with almost rainless period. Only a 36 mm rain was recorded from November 2014 to March 2015. The day to day fluctuation of wind speed was visible during the study period with a mean value of 1.14 (±1.55) kilometers per hour (Fig. 1).

Well ploughed land was fertilized with urea, triple super phosphate (TSP), muriate of potash (MOP), gypsum and zinc sulphate @ 80, 60, 48, 40 and 2 kg ha^{-1}, respectively [17]. Half of amount of urea and other doses of fertilizers were incorporated into soil during final land preparation. The remaining amount of urea was applied on 30 days after sowing (DAS). Two crops i.e., mustard and grass pea having dissimilar growth habits were used where mustard was grown as main or dominate crop and grass pea as companion crop or subordinate crop or intercrop. The names of the variety of mustard and grass pea are Binasorisha-4 and Binakhesari-1, respectively.

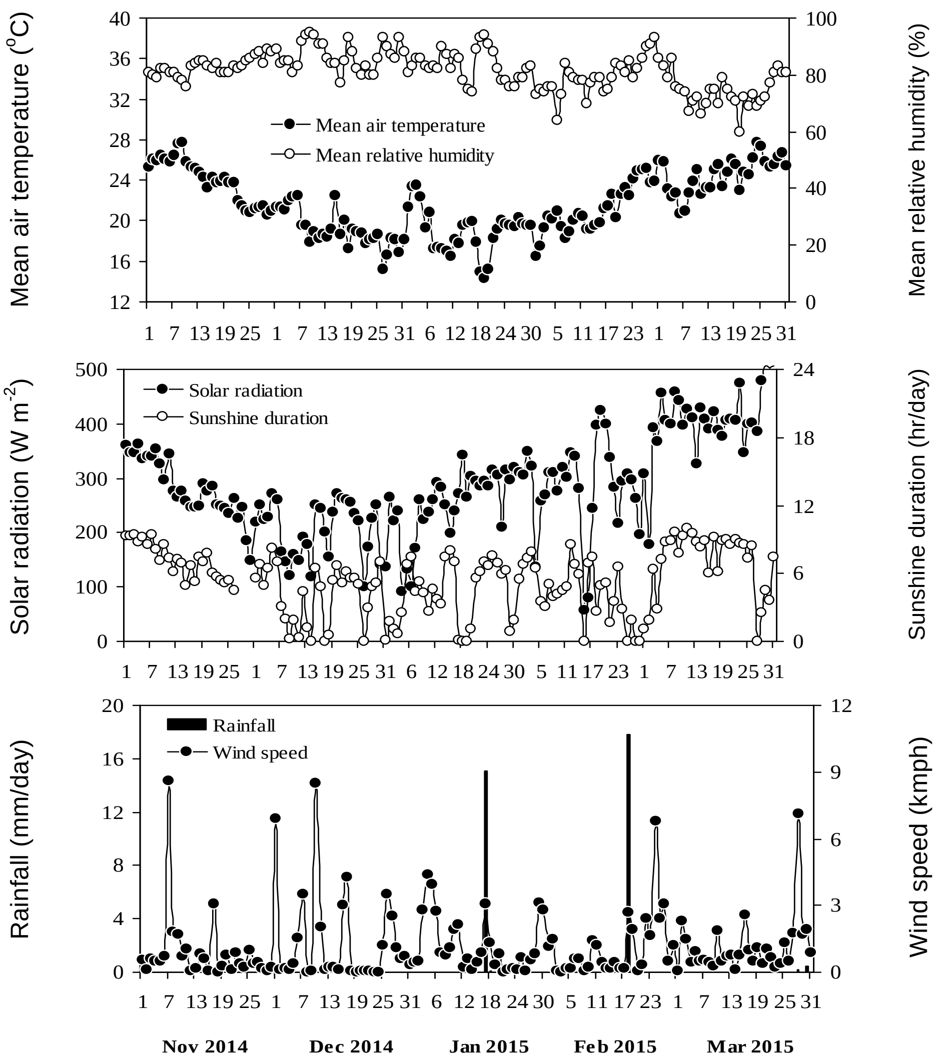

Fig. 1. Major micrometeorological variables at the experimental site prevailing during the study period

Source: Weather Yard, Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh 2202

The experiment comprised four treatments viz. (i) sole mustard crop, (ii) sole grass pea crop, (iii) alternate single row intercropping of mustard and grass pea (1M:1G), and (iv) single row of mustard followed by double row grass pea intercropping (1M:2G). Row to row spacing was 25 cm for sole mustard and grass pea crops. In 1M:1G intercropping, inter row distance of mustard crop was 40 cm where a single row of grass pea was grown centrally in between the mustard rows. In 1M:2G intercropping system, mustard rows were grown with 50 cm apart where two rows of grass pea equidistantly grown in between the mustard rows. The experiment was laid out with a Randomized Complete Block Design (RCBD) with three replicates. The total experimental area was divided into three blocks each representing a replication. Each block was divided into four unit plots keeping 1 m space between two adjacent unit plots or blocks. The size of each unit plot was 6 m×5 m.

Mustard and grass pea seeds were sown as per the design of the experiment in lines on 18 November 2015. Before sowing, the high furrows were made with a hand operated iron tine designed for this purpose to keep the seeds under the soil. After placing the seed, the furrows were covered and leveled with loose soil. After seedling emergence, first thinning operation was done on 16 days after sowing (DAS) and the second one was performed on 11 days after first thinning. Weeding was done manually two times at 15 and 30 days after sowing to keep the plots weed free. Other cultural practices including pest managements were done as and when required to optimize the growth and development of the crop.

2.2 Light Measurements

PAR transmission (T_{PAR}) through the crop canopy was recorded with a Radiometer (Model LI-189, Li-Cor, Lincoln, NE, USA) connected to a 1-m-long Line Quantum Sensor (SR.NO. LQA 1401, Li-Cor, Lincoln, NE, USA). The measurements were done only under blue-sky conditions during solar noon with no cloud cover. Percentage of PAR interception (I_{PAR}) was computed by subtracting PAR transmission from incident PAR (δ_{PAR}) which divided by incident amount of light and then multiplied by 100.

$$\%I_{\mathrm{PAR}} = \frac{\delta_{\mathrm{PAR}} - T_{\mathrm{PAR}}}{\delta_{\mathrm{PAR}}} \times 100$$

The total PAR intercepted i.e., $\sum \boldsymbol{I}_{\mathbf{PAR}}$ between two consecutive measurements was calculated as [18,19]:

$$\sum I_{\mathrm{PAR}} = \Omega\beta\left(f_{I_{\mathrm{PAR},1}} + f_{I_{\mathrm{PAR},2}}\right)/2$$

where, Ω is the summation of the total daily incident short-wave solar radiation (R_s; 0.3–3.0 mm) between the first (1) and second (2) investigation periods, and β (=0.45) is the conversion factor of R_s to yield the PAR at 0.4–0.7 mm [11]. The daily incident R_s flux was recorded at the onsite Meteorological Station, i.e., closed to the experimental area. The measurement was started from 30 DAS at about 10-days interval till maturity of crops.

2.3 Crop Sampling and Data Collection

Soon after each radiation measurement, all plants within an area of 1 m^2 were harvested for destructive sampling. The plants were uprooted carefully with an iron made fine digging device to ensure maximum volume of roots. Plant height was measured and number of primary branches (the branches that directly originated from main stem) per plant was counted. Leaf area was measured by an electronic Leaf Area Meter (LI-3000, LiCOR, LE, USA) and then leaf area index (LAI) was recorded as the leaf area/ground area (m^2 m^{-2}). The harvested material was dried to a constant weight in an oven at 80±2^{o}C. The total crop dry weight was then recorded as the sum of the weights of the root, stem, leaves, and siliqua (for mustard) or pod (for grass pea).

At physiological maturity (when siliquas or pods became straw colored) the undisturbed crop stands of 3 m2 area from each plot was harvested and bundled separately with proper tags and then brought to the clean threshing floor. The bundles were dried in open sunshine for four days, and then threshing, cleaning, winnowing and drying of seeds were done carefully. Straw was also dried properly in the sunshine. Then dry weight of seed and straw were recorded after keeping them in an oven until constant weight at 80±2℃. Data on yield components and yield for each crop species were recorded.

2.4 Computation of Radiation-use Efficiency (RUE)

The RUE of the seasonal changes (i.e., temporal) was calculated as the difference in the total crop dry weight between two consecutive measurements divided by the corresponding amount of PAR intercepted. The seasonal mean RUE was computed as the slope of the linear regression of the cumulative biomass plotted against the corresponding amount of PAR intercepted [11,20].

2.5 Calculation of Productivity Index

2.5.1 Land Equivalent Ratio (LER)

The land equivalent ratio (LER) was calculated following the formula [21]**:**

$$\mathrm{LER} = \sum_{i=1}^{n} \left(y_{\mathrm{i}}^{\mathrm{I}} / y_{\mathrm{i}}^{\mathrm{S}} \right)$$

where, $\boldsymbol{y}_{\mathbf{i}}^{\mathbf{I}}$ and $\boldsymbol{y}_{\mathbf{i}}^{\mathbf{S}}$ are the yield of crop 'I' in intercropping and 'S' in sole cropping, respectively, and ' n' is the total number of crops in the intercropping system.

2.5.2 Area time equivalent ratio (ATER)

The area time equivalent ratio (ATER) was calculated as [22]:

$$\mathrm{ATER} = \sum_{i=1}^{n} \frac{t_{\mathrm{i}}^{\mathrm{S}}}{t_{\mathrm{I}}} \left(y_{\mathrm{i}}^{\mathrm{I}} / y_{\mathrm{i}}^{\mathrm{S}} \right)$$

where, $\boldsymbol{t}_{\mathbf{i}}^{\mathbf{S}}$ is the growing period of crop 'i' in sole cropping and $\boldsymbol{t}_{\mathbf{I}}$ is the total growing period for the intercropping system.

2.5.3 Competitive ratio (CR)

The competitive ratio (CR) was calculated following Willy and Row [23] and Leihner [24]:

$$\mathrm{CR} = \left(\frac{I_{\mathrm{a}}/S_{\mathrm{a}}}{I_{\mathrm{b}}/S_{\mathrm{b}}} \right) \left(q_{\mathrm{b}} / q_{\mathrm{a}} \right)$$

where, I_a and I_b are the yield of crop 'a' and crop 'b' in intercropping, and that of S_a and S_b are the corresponding yields in sole cropping, respectively. The term q_a is the relative space occupied by species 'a' and that of q_b by species 'b' in the intercropping mixture/association.

2.6 Statistical Analysis

The collected data on different parameters were statistically analyzed to obtain the level of significance using MSTAT-C package programme. The mean differences were compared by Duncan's Multiple Range Test (DMRT) [25].

3. RESULTS

3.1 Leaf Area Index (LAI)

Leaf area index, a measure of leafiness and photosynthetic area of a crop at a particular time depends on the number of leaf production and leaf expansion rate as well as leaf growth. The ontogenetic variation in LAI of mustard and grass pea for different cropping systems has been presented in Fig. 2. Initial low LAI of mustard plants rapidly increased to a maximum at about 50 DAS followed by a sharp decline with the advancement of maturity. The LAI of mustard within different cropping systems was insignificant during early dates of harvest (up to 50 DAS) but significant for later dates ($P \leq 0.05$).

In grass pea crops, the LAI slowly increased at initial stage (Fig. 2). Thereafter the LAI was gradually and continuously increased with progress of season. Like as mustard, the LAI of grass pea crops grown with various cropping systems was found insignificant during early stages (till to 50 DAS) but significant for later dates of samplings ($P \leq 0.05$).

3.2 Accumulation of Dry Matter

Initial slower accumulation of dry matter was noticed that gradually increased with the development of the crop canopy (Fig. 3). Larger dry matter accumulation was observed at the later part of the crop growth. Combine intercrop canopy that integrates both mustard and grass pea species accumulated largest amount of dry matter as compared to any of the sole cropping ($P \leq 0.05$). Mustard stands accumulated significantly higher amount of dry mass than the grass pea canopy both in pure crops and in the intercrops ($P \leq 0.05$).

The combine 1M:2G intercrop canopy showed superiority than the 1M:1G intercropping system for dry matter production. In case of mustard, sole crop accumulated higher amount of dry matter, and mustard plant grown with 1M:2G intercropping system accumulated lower amount while the stands grown with 1M:1G produced in between (*P*≤0.05; Fig. 3). In case of grass pea crop, pure stands accumulated higher amount of dry matter followed the stands grown with 1M:2G intercropping whereas the stands grown with 1M:1G produced the significantly lower amount of dry matter.

3.3 Seasonal Fluctuation of RUE

Seasonal variation of RUE was calculated as the amount of total dry matter accumulated divided by the corresponding amount of PAR intercepted by the crop canopy. The data of seasonal variation of RUE among the treatments are shown in Fig. 4. The seasonal variation in RUE was found as much fluctuation. For each measurement, the value of RUE was highly changed for all the cropping systems. The variation in RUE among the cropping systems was found significant (*P*≤0.05). The 1M:2G combine intercrop canopy showed higher value of RUE followed by the 1M:1G combine intercropping whereas lower RUE was found for the sole grass pea canopy.

3.4 Seasonal Mean RUE

The cumulative amount of total dry matter was regressed against the corresponding amount of PAR intercepted. Regression analysis showed that the relationship between these two parameters is linear where the slope of the straight line is called radiation-use efficiency (RUE). The combine intercrop canopy of 1M:2G showed higher RUE followed by 1M:1G canopy whereas the sole grass pea stands showed minimum RUE (*P*≤0.05; Fig. 5).

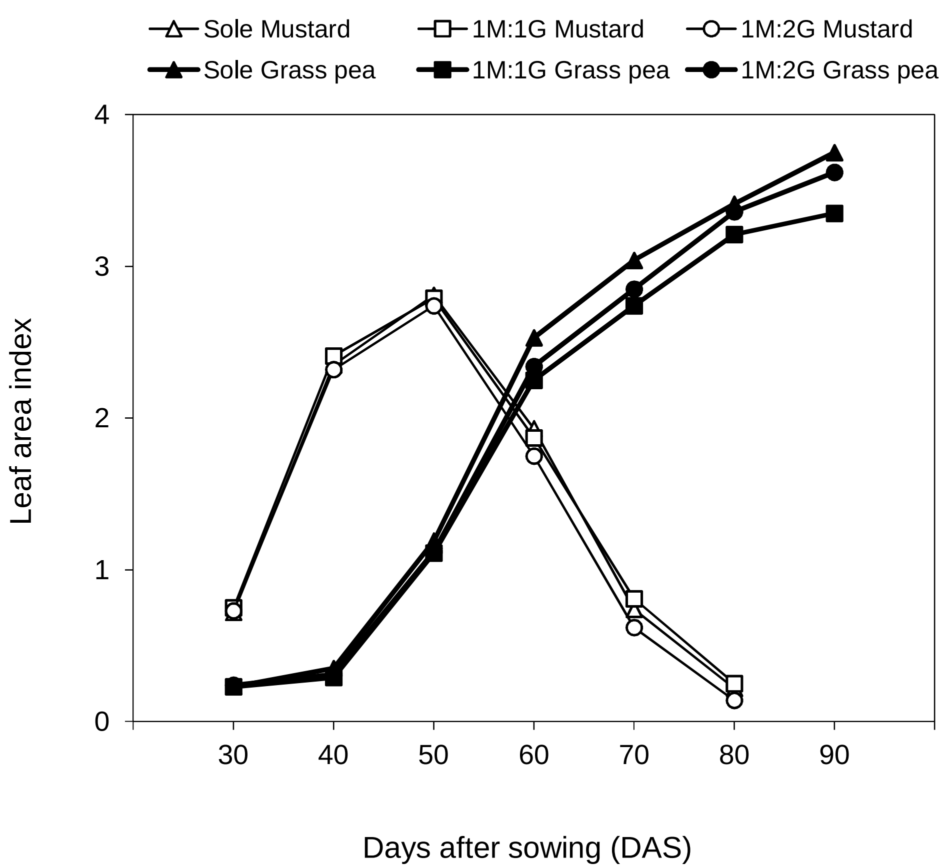

Fig. 2. Leaf area index (LAI) of mustard and grass pea plants grown as pure stands and grown with intercropping systems with time

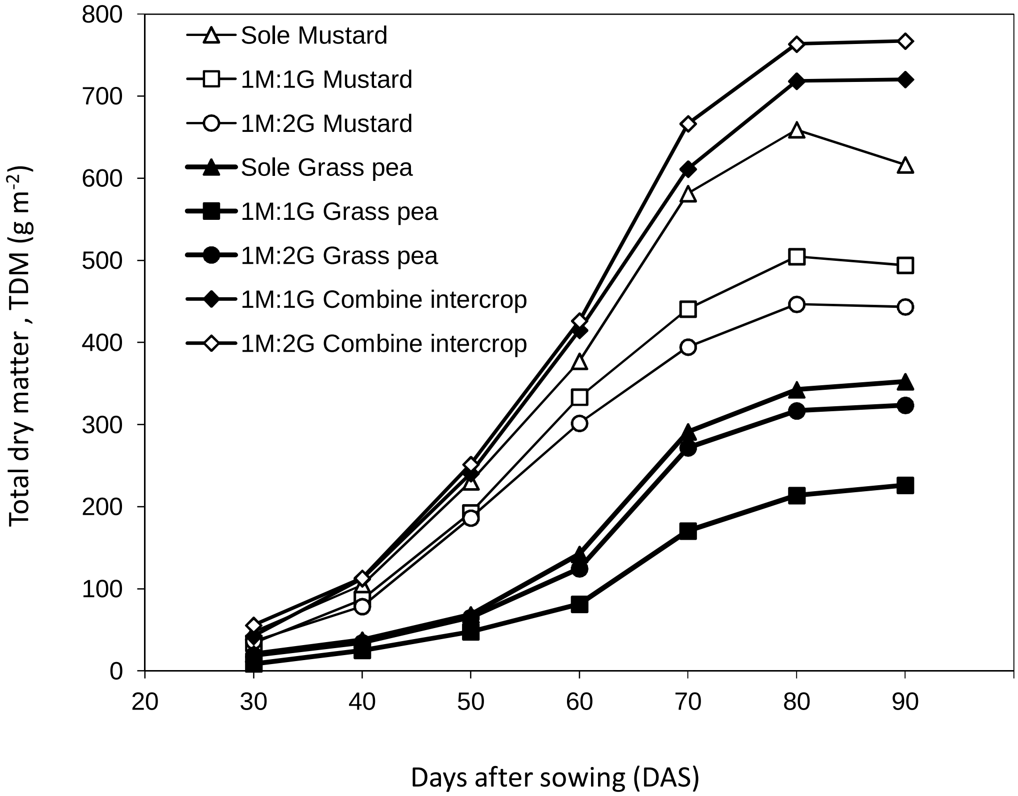

Fig. 3. Accumulation of dry matter of mustard and grass pea plant grown as pure stands and grown with intercropping systems with time

3.5 Yield Components, Yield and Harvest Index

The effect of sole and intercropping systems on the number of siliqua per plant and number of seed per siliqua in mustard is significant but insignificant for 1000-seed weight (Table 1). The number of siliqua per plant, number of seed per siliqua and harvest index are little higher in mustard plants grown with intercropping as compared to sole cropping. In contrast, grain yield and biological yield are significantly higher in mustard plants grown as pure stands than grown with intercropping system.

The effect of sole and two intercropping systems on the number of pod per plant and 1000-seed weight in grass pea was significant but it was found insignificant for the number of seed per pod (Table 2). The number of pod per plant, 1000-seed weight and harvest index were higher in grass pea plants grown as pure stands as compared to the stands grown with intercropping. The grain yield and biological yield were found significantly higher in grass pea plants grown with 1M:2G intercropping or sole cropping whereas these yield are found with lower value in 1M:1G intercropping.

A brief production summary with grain yield, biological yield and harvest index are shown in Table 3. Maximum grain yield was obtained from the combine canopy of 1M:2G intercropping system followed by 1M:1G intercropping system. The sole grass pea crop produced minimum grain yield whereas sole mustard ranked intermediate. The sole grass pea crop also gave minimum biological yield as compared to other treatments. However, grass pea crop had higher harvest index than the mustard one.

3.6 Land Productivity Indices

3.6.1 Land equivalent ratio (LER)

The LER was calculated for comparing among the mustard/grass pea intercropping systems. LER varied significantly due to the different spatial intercropping in mustard with grass pea (Table 4). In 1M:1G row intercropping system, combined intercrop results higher LER (1.493) followed by mustard (0.807) and grass pea (0.690) i.e., the 1M:1G combined intercropping mixture showed about 46 and 54% higher LER than that of mustard and grass pea components.

In 1M:2G row intercropping system, combined intercrop results the highest LER (1.663) which was about 59 and 41% higher than that of mustard and grass pea partners, respectively.

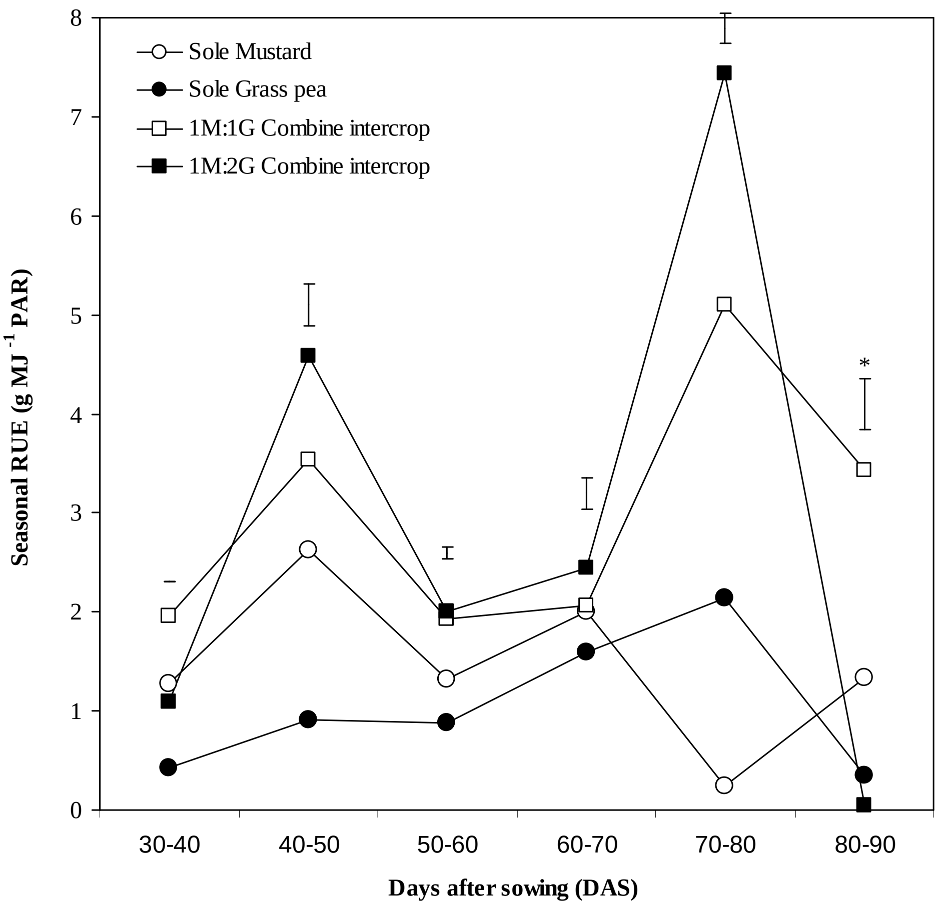

Fig. 4. Seasonal fluctuation of radiation-use efficiency (RUE) of sole and intercropping systems with time. Vertical bars represent the Least Significant Difference (LSD) among the treatments at 1% (*at 5%) level of probability

Table 1. Yield components, yield and harvest index of mustard grown as sole crop and intercropped with grass pea

Cropping system	No. of siliqua/ plant	No. of seed/siliqua	1000-seed weight (g)	Grain yield (t/ha)	Biological yield (t/ha)	HI (%)
Sole Mustard	61.43 c	20.67 b	3.92	2.320 a	7.730 a	28.01 c
1M:1G Mustard	63.32 a	22.31 a	3.95	1.873 b	5.760 b	30.58 a
1M:2G Mustard	62.46 b	21.95 a	3.93	1.600 b	5.060 c	29.41 b
$s_{\bar{x}}$	0.165	0.240	0.065^{NS}	0.075	0.060	0.293

In a column, figures followed by similar letters do not differ significantly at 1% level of probability. NS = Not significant

Table 2. Yield components, yield and harvest index of grass pea grown as sole crop and intercropped with mustard

Cropping system	No. of pod/plant	No. of seed/pod	1000-seed weight (g)	Grain yield (t/ha)	Biological yield (t/ha)	HI (%)
Sole Grass pea	16.31 a	4.54	69.12 a	1.450 a	3.430 b	38.56 a
1M:1G Grass pea	15.57 a	4.48	65.37 b	0.9933 b	2.430 c	35.61 b
1M:2G Grass pea	12.64 b	4.43	62.25 b	1.413 a	3.680 a	37.54 a
$s_{\bar{x}}$	0.205	0.141 NS	0.836	0.041	0.032	0.436*

In a column, figures followed by similar letters do not differ significantly at 1% or 5% (*) level of probability. NS = Not significant.

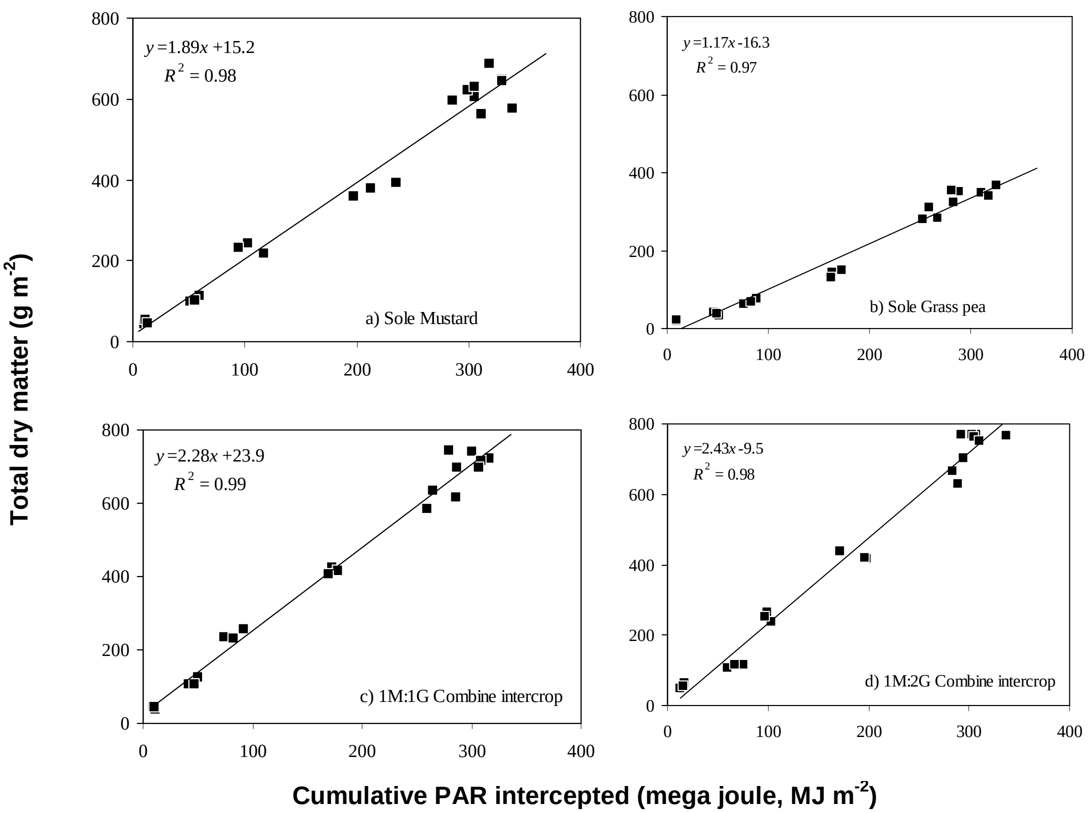

Fig. 5. Relationship between total dry matter accumulation and cumulative PAR interception of different sole and intercropping systems. The slope of the regression line represents the mean radiation-use efficiency (RUE) as g MJ^{-1}

Table 3. Economic yield, biological yield and harvest index of mustard and grass pea crops grown as pure stands or grown with intercropping

Cropping system	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index, HI (%)
Sole mustard	2.320 c	7.730a	28.01 b
Sole grass pea	1.450 d	3.430 b	38.56 a
1M:1G combined intercrop	2.867 b	8.190 a	33.10 ab
1M:2G combined intercrop	3.010 a	8.740 a	33.48 ab
$s_{\bar{x}}$	0.025	0.286	1.63*

In a column, figures followed by similar letters do not differ significantly at 1% or 5% (*) level of probability.

Table 4. Land equivalent ratio (LER), area time equivalent ratio (ATER) and competitive ratio (CR) of the partner stands of the intercrop or combined intercrop

Partner stands	1M:1G intercropping system			1M:2G intercropping system		
	LER	ATER	CR	LER	ATER	CR
Mustard	0.807 b	0.623 b	1.18 a	0.687 c	0.533 c	0.357 b
Grass pea	0.690 b	0.690 b	0.853 b	0.977 b	0.977 b	2.83 a
Combined intercrop	1.493 a	1.313 a	-	1.663 a	1.507 a	-
$s_{\bar{x}}$	0.036	0.036	0.045*	0.051	0.045	0.117

In a column, figures followed by similar letters do not differ significantly at 1% or 5% (*) level of probability.

3.6.2 Area time equivalent ratio (ATER)

ATER was significantly affected by the different cropping systems (Table 4). In single row intercropping system, combined intercrop exhibited higher ATER (1.313) which crossed the unity (1.0) and was respectively about 45 and 39% higher than that of ATER from mustard and grass pea partners. In 1M:2G row intercropping system, combined intercrop mixture showed higher ATER (1.507) which was about 65 and 35% higher than that of ATER obtained from mustard and grass pea partners, respectively.

3.6.3 Competitiveness of the partner species

Competitive ratio (CR) of mustard and grass pea under different intercropping systems was calculated and the result is presented in Table 4.In 1M:1G row intercropping system, mustard stands dominated over grass pea crop. On the other hand in 1M:2G intercropping system, grass pea plants strongly dominated over mustard.

4. DISCUSSION

For successful production intercropping needs some considerations. Silwana and Lucas [26] found that intercropping affects vegetative growth of component crops especially the subordinate partner; thus one have to consider the spatial [27], temporal and physical resources. Practically viable intercropping largely depends on adaptation of planting pattern and selection of compatible crops based on indices concerned [3,4,6,7].

When two or more crops are grown together the peak growth period of component crops is of prime importance for selecting intercrop partners. The biggest complementary effects and thus biggest yield advantages seen to occur when the component crops have different growing periods so make their major demands on resources at different times. Crops of varying maturity duration should be chosen therefore a rapidly maturity crop completes its life cycle before the major growth of other crop commence. Crops which mature at different times thereby separate their periods of maximum demand for nutrient, soil moisture, aerial space, light etc [28]. In the present mustard-grass pea association for example, peak LAI for mustard is observed on 50 DAS, while grass pea had a minimum LAI at that time (Fig. 5) which allows better radiation interception on complementary basis. The phenomenon is common for dry matter accumulation by mustard and grass pea too. Initial slower development of grass pea allows better growth of mustard plants similar to that of grown as pure stands. Hence productivity of mustard crop is almost unaffected when it is grown with grass pea. As subordinate species the growth and yield of grass pea was affected when it was grown with mustard. However, early harvesting of mustard would provide an opportunity to grass pea for better compensation during the remaining season.

The performance of component partners in an intercropping system depends on the relative spaces. In this experiment, the dominate mustard crop in mixture enjoyed wider row space than that at sole mustard resulted better individual performance. Opposite phenomenon is also common for subordinate grass pea stands where they were crowded as compared to their row space in pure stands resulted poor individual performances. The quantitative values of growth along with other traits like leaf area index, yield and yield components of mustard and grass pea crops in this experiment are within the range of those cited in the literature [29-35].

The published values of RUE of mustard and grass pea in literature are hardly available. O'Connell et al. [36] estimated RUE (aboveground biomass basis) as 1.92 (±0.12) g MJ^{-1} intercepted PAR for mustard which is very close the RUE of mustard in this study. However, there is no report found on the RUE of grass pea. Therefore, the result of the present experiment is the primer one that will be used as a new data base for the future research.

Yield is taken as primary consideration in the assessment of the potential of intercropping practices [37]. Mashingaidze [38] found that by intercropping land is effectively utilized thus combine yield is improved. The crops are grown together because of higher and greater biological and economic stability in the system [39]. Land equivalent ratio (LER) indicates the ratio of land required by pure crop stand to produce the same yield as that of intercrop. It refers to the relative area of pure crop or crops required to produce the same yield or yields as achieved in intercropping of the same crops [40]. LER is the most common index adopted in intercropping to measure the land productivity. It is often used as an indicator to determine the efficacy of intercropping [41]. LER greater than one indicates greater efficacy of land utilization in intercropping system. The 1M:2G intercropping system was found to be better than 1M:1G intercropping in response of LER and the result is corroborated with the findings of Awal et al. [6,7] for mustard/soybean and barley/peanut mixtures and Rahman et al. [8] for mustard/lentil mixture.

Due to the land occupation time by the partner stands was different, area time equivalent ratio (ATER) would provide better estimate than LER [42] and it permits an evaluation of crops on a yield per day basis [43]. In 1M:2G row intercropping system, combined intercrop mixture showed highest ATER (1.507) which was about 65 and 35% higher than that of ATER obtained from mustard and grass pea partners, respectively and the result is corroborated with the findings of Awal et al. [6]. From the data it was found that 1M:2G intercropping system showed best performance [44] as compared to the single row intercropping system. Though subordinate species grass pea crop significantly dominated over mustard as grass pea planted with double rows. Therefore, grass pea showed competitive ratio (CR) as 2.83 while CR of mustard had only 0.357.

5. CONCLUSION

It is concluded from the present study that

(i) mustard and grass pea crops are well compatible in intercrop association allowing maximum utilization of solar radiation as the radiation-use efficiency was found higher in combine intercrop canopy as compared to the individual crops grown as pure stands; and
(ii) single row of mustard followed by double rows of grass pea would be better for profitable production of these crops as yield and productivity traits are found with higher values as compared to those at alternate single row intercropping due to improved utilization of solar radiation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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