PERFORMANCE OF WHEAT-MUSTARD INTERCROPPING UNDER DIFFERENT ROW RATIOS

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CERTIFICATE

This is to certify that the thesis entitled "PERFORMANCE OF WHEAT-MUSTARD INTERCROPPING UNDER DIFFERENT ROW RATIOS" **submitted to the** *Faculty of Agriculture*, **Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of** *MASTER OF SCIENCE (M.S.) IN AGRONOMY,* **embodies the results of a piece of *bona fide* research work carried out by** *HITAISHI CHAKMA,* **Registration. No.10-03976, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.**

I further certify that such help or source of information as has been availed of during the course of this investigation has duly been acknowledged.

Dated:

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ABSTRACT

An experiment was conducted at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka from November, 2015 to March, 2016 to study the performance of wheat-mustard intercropping as influenced by different row arrangement. Ten treatments were included in this study as, T_1 (sole wheat), T_2 (sole mustard), T_3 (wheat-mustard in 2:1 rows), T_4 (wheat-mustard in 3:1 rows), T_5 (wheat-mustard in 4:1 rows), T_6 (wheat-mustard in 5:1 rows), T_7 (wheat-mustard in 2:2 rows), T_8 (wheat-mustard in 3:2 rows), T_9 (wheat-mustard in 4:2 rows) and T_{10} (wheat-mustard in 5:2 rows). The experimental result indicate that seed yield of wheat was significantly affected by the wheat-mustard intercropping system. The highest seed yield (3.4 t ha^{-1}) was obtained from T_1 (sole wheat) and T_4 (wheat-mustard in 3:1 rows). Wheat yield gradually decreased with increasing mustard rows except T_4. The lowest seed yield (1.87 t ha^{-1}) was obtained from T_7 (wheat-mustard in 2:2 rows) which was statistically similar to T_8 (wheat-mustard in 3:2 rows). The highest wheat equivalent yield (5.03 t ha^{-1}) was obtained from T_4 (wheat-mustard in 3:1 rows). Treatment T_4 (wheat-mustard in 3:1 rows) produced the highest LER which was 1.45. Economic analysis of the different treatments showed that the highest gross return (120250 Tk. ha^{-1}), the highest net return (61178 Tk. ha^{-1}) and BCR (2.04) were found in T_4 (wheat-mustard in 3:1 rows). Therefore, present study suggest that wheat and mustard intercropped in 3:1 rows is the most compatible in respect of yield advantage and economic gain.

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CHAPTER 1
INTRODUCTION

The practice of growing of two or more crops simultaneously in the same field is called intercropping. It is a common feature in traditional farming of small landholders. It provides farmers with a variety of returns from land and labour, often increases the efficiency with which scarce resources are used and reduces the failure risk of a single crop that is susceptible to environmental and economic fluctuation. Main purpose of intercropping is to produce a greater yield on a given piece of land by making use of resources in the way of maximum efficiency. The need for increased production of oilseed can also be fulfilled through their intercropping in wheat. Besides intercropping of compatible crops use resources very efficiently and provides yield advantage over sole crops. In intercropping farming system, usually one main crop and one or more were used as added crops (Saka *et al*., 2007). According to Sharma *et al.,*(1993) mixture of cereals and legumes gave higher yield than their respective sole crops. Similarly Mandal *et al.,*(1991) reported that wheat plus chickpea intercropping gave higher yield of wheat and water-use efficiency than wheat plus rapeseed intercropping. Kerrio and Aslam (1986) suggested that two crops of differing height, canopy and growth habits can be grown simultaneously with least competition. Malik *et al.,*(1998) reported that yield and yield components of wheat were significantly affected by association of chickpea, lentil and rapeseed while Mikhov *et al.,*(1991) stated that wheat yield in pure stand was significantly higher than mix cropping under rainfed conditions. Nazir *et al.,*(1988) also reported that intercropping of lentil *(Lens culinaris),* Sarson *(Brassica napus)* and chickpea *(Cicer arietinum)* decreased the wheat yield over wheat alone under in-irrigated conditions, however, the losses were compensated by their additional harvest in terms of net income.

Wheat is one of the most important crops in the world as well as Bangladesh. In Bangladesh wheat is next to rice among cereal crops where about 4,36,814 hectare of land is covered by wheat producing 13,47,926 metric ton with an average yield of 3.086 t ha^{-1} during the year 2014-2015 (BBS, 2015). According to FAO (2013) about 65% of wheat crop is used for food, 17% for animal feed and 12% in industrial applications. In one cup of whole wheat grain contains 33% protein, 29% carbohydrate, 5% fat. It has been predicted that demand for wheat in the developing world is projected to increase 60% by 2050 from now (CIMMYT, 2013).

Mustard (*Brassica* spp.) is one of the most important oilseed crops throughout the world after soybean and groundnut grown usually under rain-fed and low input condition. It has a remarkable demand for edible oil in Bangladesh. It occupies first position in respect of area and production among the oilseed crops grown in this country. In the year 2014-15, it covered 325053.441 hectare land of total crop area and the production was 145527.126 ton (BBS, 2015).There is very little scope of expansion for mustard and other oilseed acreage in the country, due to competition from more profitable alternative crops. The cultivation of mustard has to compete with other food grain crops have shifted to marginal lands of poor productivity. With increasing growth rate of population, the demand of edible oil is increasing day by day. It is, therefore, highly accepted that the production of edible oil should be increased considerably to fulfill the demand of the country.

There is need to develop the best cropping pattern to increase the production of mustard and wheat crop concomitantly. It has been shown that intercropping helps in increasing farm income (Kalra and Gangwar, 1980) while Mandal *et al.*,(1985) reported that intercropping of wheat, mustard and chickpea decreased number of fruiting branches per plant, number of pods per plant and 1000 seed weight. Sharma *et al.*,(1986) reported that plant density showed significant difference by intercropping of wheat and mustard comparing to mono culture where the highest land equivalent ratio (LER) was obtained by intercropping wheat and rape in a 1:1 row ratio. Singh and Pal (1994) reported that intercropping of wheat and mustard reduced the seed yield than their pure stands. Whereas, Ayisi *et al.*,(1997) concluded from their experiment on canola-soybean intercropping that seed oil content increased compared with sole cropping. Likewise, Verma *et al.*,(1997) reported that intercropping of wheat and Indian mustard gave maximum net return, benefit-cost ratio and land equivalent ratio.

Intercropping provides an efficient utilization of environmental resources, decreases the cost of production, provides higher financial stability for farmers, decreases pest damages, inhibits weeds growth more than monocultures, and improves soil fertility through nitrogen increasing to the system and increase yield and quality (Francis *et al*., 1976; Willey, 1979). It is now clear that the weeds could interfere with crops by increasing competition (for light, water, nutrients and space) and/or allelopathy. Weeds declines many of crops yields and it lead to higher cost in agricultural productions (Wanjari *et al.*, 2001; Pandya *et al.*, 2005; Singh and Giri, 2001). One of the most advantages of using herbicides is simplified weed control, but the use of herbicides, not only is costly but also selection of herbicide-resistant weed biotypes seriously become an environmental contamination factor now a day. Herbicide use reduction is one of the main target of sustainable, and so several alternatives being investigated, including inter-cropping. The allelopathic potentiality of *Brassica* to control weeds in wheat field was also reported (Rahman *et al*., 2012; Biswas *et al*., 2013&2014; Biswas *et al*., 2014). A primary challenge for researchers is in understanding the processes and mechanisms underpinning intercropping and the goods it delivers. Such knowledge could allow manipulation of intercropped systems to maximize desired outcomes such as food production, landscape quality or biodiversity conservation and thus promote its wider uptake.The objective of this study was therefore to investigate the feasibility, weed suppression and yield advantage of intercropping mustard in wheat under different row ratios.

Objectives

This piece of research work was frame to achieve the following objectives:

(i) to compare the performance of intercropping with different row ratios of wheat and mustard

(ii) to determine the possibility of increasing monetary advantage with intercropping

(iii) to find out the way (s) of disseminating the suitable intercropping combination of wheat and mustard to the farmers.

CHAPTER 2
REVIEW OF LITERATURE

Intercropping is an age-old practice of growing two or more crops simultaneously in the same piece of land. It is a technique of crop intensification in both time and space wherein the competition between crops may occur during a part or whole of crop growth period. It has been a common practice followed by the farmers of India, Africa, Srilanka, West Indies and Bangladesh.Crop production potential in sole cropping or in intercropping is determined primarily by the economic yields of the component crops in their growing environment. Production potentiality may also be denoted in terms of yield advantage, resource expense advantage or resource expense efficiency. Literature pertaining to production potential of wheat oriented intercropping with mustard as related to growth factors were reviewed. When ample information on the main crop and intercrops related to the growth factors were not available, relevant literatures on other crops were also cited.

2.1. Effect on plant growth and development

Singh *et al.*(1995) worked on wheat + mustard intercropping with various row ratios *viz.* 3:1, 6:1, 9:1, 3:2, 6:2 and 9:2 recorded minimum number of branch plant^{-1} of mustard at 3:1 row ratio and the maximum at 9:2 row combinations. However, the difference among various row ratios did not prove significant.

Awal *et al.* (2007) conducted an experiment to study the effect of barley/peanutintercropping on the interspecies competition, growth and yield performance of the crops and observed that plant height, leaf number, tiller or branch number per plant, leaf area index, total dry matter per plant and grain or seed yield were significantly affected by the different intercropping systems and were maximum in sole barley as well as in sole peanut while those were minimum in barley + peanut (1:1).

Mehdi (2013) worked on barley + lentil intercropping and the results showed that the highest plant height for lentil (36.3 cm) was recorded in plots where 2 rows B + 4 rows L were sown but the maximum plant height for barley (62 cm) was recorded in plots where 4 rows B + 2 rows L were sown. Minimum plant height for lentil (17 cm) was recorded in plots of sole lentil, but Minimum Height plant for barley (53.3 cm) was recorded in plots where 2 rows B + 4 rows L were sown.

Mandal *et al.*(1985) conducted an experiment and confirmed that treatments involving wheat, mustard and chickpea grown alone, or wheat in combination with mustard and chickpea affected branching and plant height in mustard and chickpea.

Mandal *et al.* (1991b) reported that the maximum DM was recorded in wheat + mustard intercropping at 90 days after sowing grown in 4:2 row combinations.

Mohammadi *et al.* (2012) studied intercropping of barley + fenugreek involving treatments of sole barley, sole fenugreek, and an additive intercropping series as 10, 20, 30, 40 and 50% of the seed rate of barley mixed with fenugreek seed rate. The results showed that the maximum biomass and leaf area index (LAI) of barley and fenugreek was recorded at the 10 and 20% of additive intercropping while the lowest amount of those traits was obtained in the 50% additive of barley.

Prasad *et al.* (1978) observed that the barley + peanut intercropping variation of LAI among the treatments could mainly be attributed to the variation of tillers/hill or branches/plant and number of leaves/plants. Initial poor vegetative growth resulted insignificant variation in LAI.

Ali *et al*. (2000) evaluated canola based wheat intercropping. The study showed that the different intercropping patterns also had a highly significant effect on a number of fruiting branches per plant. Maximum numbers of fruiting branches per plant (18.30) were found in case of canola planted alone and differed significantly from rest of the other planting patterns. However, the minimum number of fruiting branches (14.10) was recorded in case of canola planted with three rows of wheat and remained statistically on which differed significantly from rest of the treatments.

Awal *et al*. (2007) reported that the dry matter (DM) production was different at different growth stage. TDM production was affected significantly by intercropping treatments. The DM in peanut increased slowly when grown with barley till 100 DAS but after harvesting of the main crop (barley) at 100 DAS, the DM increased sharply till harvesting. Sole barley and peanut accumulated maximum DM throughout the growth period followed by the plants grown under barley + peanut (1:1) and barley + peanut (1:2) treatments.

Gill *et al*. (2009) experimented mixed cropping of wheat and chickpea on their growth and nodulation in chickpea. When grown in mixture, wheat had an inhibitory effect on root proliferation, total biomass and grain yield of chickpea; the value of different parameters in mixture being one third of that determined when chickpea was grown as a sole crop. The inhibition intensified with time and severity of damage to chickpea roots maximized at maturity as suggested by a sharp decrease in root/shoot ratio contrary to chickpea, biomass yield of wheat increased by >100% due to the companion crop. The improvement was observed in all the plant components but harvest index and greenness of flag leaf was not affected.

Musa *et al.* (2010) reported that the leaf area indices of peas were smaller than those of barley and when grown in combination with barley and it were similar to what might be expected from a 50/50 replacement series *i.e.*, half the value of the sole crop. Combined leaf area indices of all the barley/pea mixtures were similar, all significantly lower than the sole barley crop, but all significantly greater than the sole pea crop. Total dry matter was greatest with the barley/pea intercropped mixtures planted as mixed rows or cross when planted in mixtures were also significantly reduced, when compared with the sole crop, but increased when compared with half the yield of the sole crop.

Srivastava and Verma (2007)at Varanasi (Uttar Pradesh) observed that association of wheat with mustard under 8:1 row ratio recorded the maximum values in terms of Leaf Area Index (LAI) and DM accumulation of both the crops but the magnitudes of these parameters decreased markedly in 5:1 and the minimum was with 2:1 row ratio, whereas harvest index of wheat decreased significantly from 8:1 to 2:1 row ratio.However, the difference among treatments in respect to LAI and DM in both the component crops was highly pronounced at 60 days after sowing and onwards. On same pattern, growth attributes of both crops in various treatments was manifested in yield attributes and eventually reflected in biological, seed and grain yields.

Kolvanagh and Shokati (2012) studied intercropping two types of medicinal plants Dill andFenugreek in different additive ratio (1:20, 1:40, 1:60) and different replacement ratio (1:1, 1:2, 1:3). Dill by enough using of space and better using of N which were fixed by fenugreek root, in additive ratio could grow better than replacement ratio and have significant dry weight, stem dry weight, height and number of umbel where 1:20 and 1:60 ratio had highest records. But fenugreek as same as dill because of having enough space in replacement ratio could grow better and had significant dry weight, secondary fertile branch, stem dry weight and main stem number where in 1:3 and 1:2 ratio had highest record respectively.

Li *et al*. (2009) reported that upland rice/mung beanintercropping improved the formation of arbuscular mycorrhizas, in the upland rice roots.The authors reported an improved formation of mycorrhizas by the intercropping increased total P uptake by 57% in rice, total P and N acquisition by 65% and 64% respectively in mung bean, and nodulation by 54% in mung bean.

Li *et al*. (2001) observed wheat/maize and wheat/soyabean intercropping showed a clear advantage over sole cropping in terms of biomass and nutrient accumulation.

Li *et al.* (2011) studied intercropping system of wheat/ maize, wheat/ feba beanand maize / feba bean. They observed that by using species having different maturity dates can be more effective in decreasing soil mineral nitrogen accumulation and increasing crop nitrogen use efficiency.

Liebman and Dyck (1993) concluded that land equivalant ratio resulted into an increase when intercrops are seeded at higher densities.

Raouf *et al.*(2003) carried out field experiment on intercropping oftwo wheat cultivars; one was tall (110 cm.) and other wasdwarf (65 cm.). They observed that both cultivars were grown with sixsowing ratios and 3 seeding densities. They observed9.13% higher yield in sowing ratio of 40:60 grown atseeding density higher than optimum. This yield wasgreater than maximum yield which was obtained inmonoculture of one of tall cultivar.

Gill *et al.* (2009) reported that intercropping of chick pea and wheat was done in several countries but mutual affects of both crops on root proliferation is hardly reported.

Yang *et al.* (2010) observed the effect of strip intercropping of wheat and maize with width of 80cm each. They observed more root development at most of soil depth and yield advantages in intercropping system compared to sole crop.

Li *et al.* (2001) observed recovery of maize growth in wheat/maize intercropping after harvesting wheat. Rate of dry matter accumulation in maize was lower initially but increased after wheat harvest.

Wang *et al.* (2009) carried out an experiment with wheat, soybean and oat as intercrop in cucumber and observed that cucumber intercropping wheat showed best results and promoted cucumber growth and yield.

Akter *et al.* (2004) studied the performance of mixed and intercropping of wheat and lentil and concluded that line sowing performed better than sole broadcast sowing. They also observed that lentil, wheat mixed seed rate decreased lentil yield over sole lentil crop sown through broadcast method.

Gill *et al.* (2009) carried out an experiment on pot to explore the effectof mixed intercropping of wheat and chickpea andconcluded that wheat has inhibitory effect on totalbiomass, root proliferation and grain yield of chickpea.

Gao and Wu (2014) carried out an experiment on wheat-maize intercropping system and revealed that Nitrogen use efficiency was significantly higher in intercropping compared to sole cropping.

Zhang and Li(2003)conducted field experiments onintercropping wheat- maize and wheat-soybean and observed that there was increase in uptake of nitrogen up to 50 and 59%, respectively in case of wheat-maize intercropping, respectively and 23 and 19% in case of wheat-soybean intercropping respectively.

Barillot *et al.* (2014) found significantly higher radiation use efficiency in wheat pea when intercropped than that of sole crop. It was attributed to above ground and below ground interaction.

Ali (1993) conducted field trials onintercropping wheat/chickpea and observed that 2:2 row resulted in more light interception and transmission to lower canopy which resulted in more land equivalent ratio and yield.

Eskandari (2011) conducted a study on intercropping affect of wheat and faba bean and described that intercropping system had a marked effect on environmental resource utilization in terms of more light interception, water and nutrient uptake compared to sole crop.

2.2. Effect on yield attributes

Mandal *et al.* (1985) noticed in an experiment involving wheat and mustard grown alone or in wheat combination with mustard that the number of ear-bearing tillers in wheat was highest when grown alone and number of spikelet and grain ear^{-1} markedly reduced in combination with mustard. Similarly, intercropping reduced the number of siliqua plant^{-1} in mustard.

Sharma *et al.* (1986) conducted an experiment on a sandy clay loam soil of Pantnagarduring winter season. Treatments comprised of seed mixture of wheat andmustard in 1:1, 2:1, 3:1, 5:1; one row of wheat alternated with one mustard row; 4, 6 and 10 wheat rows alternated with 2 rows of mustard as well as pure wheat and mustard. It was observed that the adverse effect of mustard on wheat was enhanced with its increasing population. Grains spike^{-1} of wheat was reduced slightly due to inter-row competition of mustard. However, 1,000 grains/seeds weight of wheat and mustard and siliquae plant^{-1} of mustard remained unaffected in intercropping.

Singh *et al.* (1995) reported that the number of shoot or spike bearing tiller of wheat m^{-1} row length was the highest under pure stand and decreasedsignificantly when the wheat was grown in any combination with Indian mustard.

Srivastava and Bohra (2005) reported that increasing proportion of Indian mustard from 8:1 to 2:1 row ratio of wheat + mustard intercropping, markedly reducedgrains spike^{-1}, effective tillers/m and 1000-grain weight of wheat, whereas siliquae plant^{-1} were highest under 8:1 row combination and reduced significantly with an increase in mustard population. This can be ascribed to the greater competition exerted by dominant Indian mustard crop on wheat and thereby utilized light, space and nutrients more efficiently.

Musa *et al.* (2010) carried out an experiment and found that number of grains per ear in barley and seeds per pod in peas was unaffectedby intercropping and planting arrangement. Harvest index remained un-affected by treatment. The increased yields of the components of the intercrop species compared with expected (*i.e.*, half the sole crop yield) were the result of a greater number of ears m^{-2} in barley and pods m^{-2} in peas. There was an indication that this effect was influenced by planting arrangement in barley, where the effect was greater in the mixed and cross drilled treatments than in the alternate rows treatment, but this was not the case for peas.

Megawer *et al.* (2010) found that all barley, lupin and chickpea traits weresignificantly affected by intercropping patterns *i.e.*, sole crop, barley/chickpea or lupin in 1:1, 2:1 and 2:2 intercropping. Barley spikes m^{-2} as well as spike grain number and weight were affected by legumes species. Solid planting of each crop surpassed all intercropping patterns for almost all studied traits. But, barley /lupin of 2:2was the best among all intercropping patterns, where it produced 93 and 60% of solid lupin seed weight/plant and yield/feddan, respectively. Superiority of solid chickpea traits reflected it’s more influencing by intercropping than lupin, due to greater competition of barley. The greatest and heaviest barley grains/spike was obtained from barley/chickpea, while the greatest number of spikes m^{-2} were produced by barley/lupin, due to different legumes growth habit. The combination 2:1 barley/chickpea or lupin had heaviest weight of grains/spike (103% of sole) and acceptable yield/feddan (83% of solid barley). Greatest number of grains/spike (53.1) and the heaviest weight of them (3.249) were obtained from barley intercropped with chickpea, while the greatest number of spikes m^{-2} was produced by barley intercropped with lupin.

Wasaya *et al.* (2013) ascertained the intercropping between wheat and fenugreek. They found that all the intercrops reduced number of tillers m^{-2}, number of grains per spike, weight of grains per spike, 1000-grain weight and grain yield of wheat significantly compared to its monocropping, nonetheless, the additional yield obtained from each intercrop compensated more than the losses in wheat production. The highest yield advantage (38%) in wheat+3 rows of fenugreek followed by wheat +4 rows of fenugreek (33 %) against the minimum of 19% in wheat+1 row of fenugreek.

Thakur *et al.* (2000) reported that the yield attributes of all intercrops (mustard,safflower and linseed) increasedcompared to their sole crops under intercropped stands.These parameters were generally superior in 6:2 row proportions than that of 3:1 row system.

2.3. Effect on yield

Sahota and Sukhdev (2012) evaluated the effect of intercropping barley and pea on grain yield and economic returns. Compared to barley and pea as sole crops, grain yield with barley-pea intercropping was greater by 266 kg ha^{-1} with alternate row combination and by 223 kg ha^{-1} when both crops were grown in the same row.

Sukhdev (2012) evaluated the effectiveness of intercropping of barley or canola with pea in improving crop yield, seed quality. Average seed yields of barley-pea intercrops were usually greater than those of barley, canola as sole crops.

Azar *et al.*(2013) studied the effect of barley-chickpea intercropping with different combinations (1:1, 2:1, 3:1, 2:2 and 3:2 row ratios of barley: chickpea) and their monocultures. The results indicated that the highest yield was obtained from combination of one row barley and one row desi chickpea. The highest number of pods was obtained, also, in combination of one row barley and one row desi chickpea. The correlation coefficient analysis indicated that number of pods per plot had the highest positive relationship with yield per plot. The path coefficient analysis showed that the number of pods had the highest direct effect on yield percentage via the number of pods.

Naeem *et al*. (2013) experimented on sole wheat, sole canola, one wheat row alternatingwith one canola row, two wheat rows alternating with two canola rows, four wheat rows alternating with four canola rows and mixed intercropping of wheat + canola (broadcast method). The results revealed that yield and various yield contributing traits of wheat and canola were influenced significantly by different intercropping treatments.

Willey and Osiru (1972) conducted a number of experiments and observed that the yield differences in intercropping comparisons may be due to changes in plant population. However, it is not surprising that some benefit from intercroppingcan be claimed under one range of plant populations.

Zhang and Li (2003) noticed that in case of wheat/ maize and wheat/ soybean intercropping system, there was significant increase in yield up to 74% and 53% in intercropped wheat with maize and soybean respectively compared to sole crop. It is likely the result of inter-specific competition for nutrients as wheat has higher competitive ability than that of maize or soybean.

Gooding *et al.* (2007) carried out field experiments on intercropping of wheat and faba bean and they observed a clear reduction of wheat yield up to 25 -30% compared to sole wheat crop.

Mandal *et al.* (1991b) obtained 588 kg $ha^{-1}$of mustardseed yield in wheat + mustard intercroppingwith 4:2 row ratio as compared to 1,556 kg ha^{-1} in its sole stand.

Chaudhary and Bhatia (1992) during 1978-79 to 1985-86, examination studied the relative effect of growing wheat with mustard under All India Coordinated Agronomic Research Project revealed that different mixed ratios, led to yield loss for wheat mostly in the range of 30-40 percent. However, the crops grown underintercropping systems with 2:1 and 3:1 row ratios showed relatively less yield loss in wheat crop. It means intercropping of wheat and mustard under specific row ratio had favourable conditions for higher yield advantage as compared to theirmixed systems.

Singh and Gupta (1994) at Pantnagar, conducted an experiment, it has been found that the maximum reduction in wheat grain yield (63.34%) occurred in 1:1 row ratio, whereas it was, 25.28%, in 10:2 wheat-mustard row system.

Nazir *et al.* (1988) experimented the biological intercrop relationship in different wheatintercropping systems comprising wheat alone, wheat-berseem, wheat-lentils, wheat-gram,wheat-mashbean, wheat-mungbean, wheat-methra, wheat-linseed, wheat-sarson and wheatgarlic was determined under field conditions on a sandy clay loam soil. The grain yield of wheat was reduced by 2.6, 11.6, 12.1, 13.6, 15.8 and 18.6% with intercropping of garlic, linseed, lentils, methra, sarson and gram, respectively, whereas relaying of mash bean and mungbean tended to increase it. However, the losses in wheat production by the respective intercrops were compensated substantially by their additional harvest in terms of net income/ha.

Nielson *et al.*(2003) noticed the effect of sole and intercropped of field pea and spring barley. The pea-barley intercrop yielded 4 Mg grain ha^{-1} which was 0.5 Mg lower than the yield of sole cropped pea but 1.5 Mg greater than harvested in sole cropped barley.

Abu-Bakar *et al*. (2014) observed the relative performance and profitability ofbarley-based intercropping systems and reported that all the intercrops decreased the grain yield of barley over sole cropping and minimum reduction in grain yield of barely was observed when it was intercropped with lentil (8.74%), while maximum reduction (17.85%) was recorded when barley was intercropped with fennel. However, barley appeared to be dominant crop as was indicated by its higher values of relative crowding coefficient, competitive ratio and positive sign of aggressivity.

Nazir *et al*. (1996) studied barley based intercropping systems. Three rows of eachintercrop (lentil, chickpea, fenugreek, linseed and wheat) were sown between the barley strips although all the intercrops reduced grain yield of barley significantly compared to its monocropping, yet the additional yield obtained from each intercrop compensated more than the losses in barley production. The land equivalent ratio showed 28 to 45 % yield advantage of different intercropping systems over sole cropping. The highest yield advantage (45 %) was recorded in barley + lentil followed by barley + gram (38 %) against the minimum of 28 % in barley + methra and barley + wheat. Similarly, all the intercropping systems gave substantially higher net income ha^{-1} over pure stand of barley.

Khaliq *et al*. (2001) studied of lentil + wheat intercropping systems and concluded that Lentil alone and wheat alone produced their maximum respective grain yields of 10.99 and 42.10 q ha^{-1} as compared to those recorded in various intercropping systems.

Tahir *et al.* (2003a) studied canola in different intercropping with wheat, chickpea,lentil and linseed along with their sole crop. They found that the all the intercrops significantly reduced their yield components, seed and oil yield of canola as compared to canola alone. Maximum reduction in seed yield of canola was observed when it was intercropped with two rows of wheat.

Ghaley *et al.* (2005) carried out an experiment to study the sole and intercropping of field pea and spring wheat on crop yield and fertilizer and soil nitrogen use.

Three levels of urea fertilizer were used i.e. 0, 4 and 8 g nitrogen m^{-2}. It was revealed that intercropping of pea and wheat resulted into maximum productivity without addition of nitrogen fertilizer.

Khan *et al.* (2005) studied on chickpea, lentil and rapeseed in intercropping with wheat. Among different ratios of intercropping, the chickpea intercropping in 1:1 ratio gave the highest grain yield (1721 kg ha^{-1}) of wheat while the lowest yield of 1213 kg $ha^{-1}$was obtained from wheat + rapeseed intercropping in 1:1 ratio.

Woldeamlak *et al.* (2009) observed that increased yield up to 122% compared tosole crop for different combination of different varietiesin barley-wheat intercropping and concluded that barley- wheatintercropping system is more efficient due tomaximum utilization of resources.

Nazir *et al.* (2002) conducted anexperiments on wheat-sugarcane intercropping with 90 cm spaced double rows and reported reduction in cane yield up to 18% but net income was enhanced due to additional harvest of wheat than sole crop.

Singh *et al.* (2000) observed that mean reduction in wheat grain yield upto 44.89 % in case of intercropping with potato after earthing up.

Qayyum *et al.* (2011) reported reduction in weed density in case of intercropping of wheat, onion and garlic in 4:2 rows strips. Maximum grain yield (5.17 t ha^{-1}) was obtained in sole wheat crop and minimum (2.23 t ha^{-1}) from intercropping of wheat and garlic in 3:2 row strips but total biomass yield in intercropping system was fairly high enough to compensate losses.

Woldeamlak *et al.* (2008) studied in an experiment that mixed cropping was more stable than sole cropping in case of wheat and barley and concluded that yield stability was more in case of mix cropping of wheat and barley.

Dua *et al.* (2007) evaluated that wheat-potato relay intercropping systemand concluded that yield of potato was not influenced byrelay intercropping but highest grain yield was obtainedin sole wheat crop.

Li *et al.* (2001) noticed intercropping is advantageous in terms of yield and nutrient acquisition. They observed that it was advantageous up to 40-70% in case of wheat intercropped with maize and 28 -30% in case of wheat intercropped with soybean.

2.4. Effect on Land Equivalent Ratio (LER)

Singh and Jodha (1989) found that the land equivalent ratio for barley and mustard intercrop was 1.04 and 1.20.

Chaudhary and Bhatia (1992) conducted an experiment using three row intercropping treatments of wheat + mustard viz. 1:1, 2:1 and 3:1. Wheat + mustard (3:1) intercropping produced maximum LER at R. S. Pura (Jammu and Kashmir), Faizabad (U.P) and Navsari (Gujarat). However, 2:1 and 1:1 row ratio of wheat + mustard recorded highest LER values over rest treatments at Pantnagar (U.P.) and Kalyani (W.B.), respectively.

Singh and Gupta (1994) evaluated wheat + mustard intercropping at Pantnagar. Among the four row ratios compared in the experiment, the maximum LER of 1.21 was recorded in 10:2 row ratio followed by 1.18 in 4:2 row ratio. However, 1:1 row ratio proved most inefficient as it recorded the lowest LER of 1.09, even though it registered the yield advantage of 9 per cent.

Bora (1999) carried out an experiment on wheat + mustard intercropping and found that the higher LER value was correlated with the higher partial LER values for both the component crops, indicating less competition between them or complementary effect of one crop on the other.

Nielson *et al*. (2003) analyzed that under field pea (*Pisum sativum* L.) and spring barley (*Hordeum vulgare* L.) intercropping the land equivalent ratio (LER) showed that plant growth resources were used from 17 to 31% more efficiently by the intercrop than by the sole crops. Pea increased the N gained from N_2 fixation from 70% when solely cropped to 99% of the total aboveground N accumulation when intercropped.

Tahir *et al*. (2003a) conducted an intercropping experiment of canola, wheat, gram, lentil and linseed, which were compared with sole cropping of canola for two consecutive years. Relative crowding coefficient (RCC) reflected that maximum K (4.08) was obtained from canola + one row of wheat intercropping system. Aggressivity (A) values - 0.03 and 0.06 indicated that wheat was the most competitive crop to canola. Similarly, competitive ratio (CR) 0.82 and 0.51 showed that among intercrops, wheat proved to be a better competitor than other intercrops when grown in association with canola.

Nargis *et al*. (2004) evaluate the performance of lentil–wheat intercropping system and foundpositive variation in different yield contributing characters of lentil and wheat.

Srivastava and Bohra (2005) reported that the intercropping of wheat with Indian mustard under 5 :1 row ratio was found more sustainable, as it accounted for higher value in terms of land-equivalent ratio (LER) and relative crowding coefficient (1.690) and was economically more remunerative.

Awal *et al*. (2007) investigated that intercropping of peanut with barley exhibited a remarkable change in land equivalent ratio (LER) and the highest LER (1.18) was obtained from barley + peanut (1:2), followed by barley + peanut (1:1) (1.07) intercropping, i.e., land-use efficiency was increased by 18% for barley + peanut (1:2) and 7% for barley +peanut (1:1).

Agegnehu *et al*.(2008) evaluated that the mixed intercropping wheat (*Triticum aestivum* L.) with faba bean (*Vicia faba* L.), they obtained the highest total grain yield of 4031 kg ha^{-1},gross monetary value of US$ 823, system productivity index of 4629 and crowdingcoefficient of 4.70 when wheat at its full seed rate was intercropped with faba bean at a rate of37.5%.

Intkhab *et al.* (2009) at the University of Agriculture, Faisalabad investigated the behaviour of component crops in different barley based intercropping systems. The intercropping systems were barley alone, barley + lentil, barley + gram, barley+ methra, barley + linseed, barley + canola. The base barley crop was sown in 75cm spaced 4- row strips with intercrops seeded between these strips. In all systems at different nutrient levels barley was dominant over all intercrops except canola in barley + canola system, where it proved to be better competitor. Barley showed higher values of aggressivity (+0.07), relative crowding coefficient (10.10) and competitive ratio (1.43) in barley + lentil intercropping system, while in barley + canola system, canola showed higher values of +0.43, 7.83 and 3.29 for aggressivity, relative crowding coefficient and competitive ratio, respectively.

Megawer *et al.* (2010) reported that land equivalent ratio, competitive ratio, relative crowding coefficient and aggressivity which revealed that barley was stronger competitive than legumes, lupin was more competitive than chickpea, and barley was dominant and each legume crop was dominated.

Yahuza (2011) determined that several growth indices for estimating intercrop performance compared to the component sole crops and concluded that in addition to the LER, for certain intercrops such as wheat/faba bean system that has not been widely adopted, there may be a need to use other indices such as ATER, CPR, CPRT and MA as may be applicable in order to understand more fully the nature of intercrop benefits that may exist. Indeed such type of information may help to attract potential growers.

Singh and Bohra (2012) studied on wheat + mustard intercropping in a 5:1 row proportion, resulted in the best land utilization , maximum productivity and monetary advantage.

Mehdi (2013) found that higher LER in intercropping treatments indicated in yield advantage over mono cropping due to better land utilization. Partial LER of Lentil decreased as the proportion of barley increased in mix - proportions. The highest of LER for economical yield was obtained at 3 row barley + 3 row lentil (2.61) and the least of LER was obtained by 2 row barley + 4 row lentils. Thus, it can be concluded that mixture were advantageous compared to both sole crops of barley and lentil. The mean LER values were always greater than 1.0.

Wasaya *et al*. (2013) found that land equivalent ratio (LER) resulted19 to 38% yield advantage of wheat + fenugreek intercropping system than sole cropping of wheat.

Abu-Bakar *et al*. (2014) found in an experiment that all intercrops gave more economic returns thansole cropping of barley; however, on the basis of land equivalent ratio, maximum yield advantage was recorded in barley + lentil intercropping system.

Bantie *et al*. (2014) studied intercropping of lupine with wheat, barley and finger millet and found that values of ATER showed 4.9% - 31.3% and 11.1% - 37.8% advantage in lupine - wheat and lupine - finger millet combinations, respectively, whilst lupine - barley combinations showed ATER of 54.5% - 60.9% disadvantage. CR showed dominancy of wheat and barley over lupine while lupine was higher CR than finger millet. Positive MAI values were recorded in lupine - wheat and lupine - finger millet mixtures indicating that these intercropping systems were a definite yield advantage and the most profitable as compared to sole cropped.

Sadullah and Shukri (2014) evaluated an experiment on wheat lentil mixed cropping and results showed that the highest land equivalent ratio (LER) for total grain and straw yields were observed in the mixed cropping treatment of wheat (100 kg ha^{-1}) + lentil (40 kg ha^{-1}).

Banik *et al.* (2005) evaluated an experiment on intercropping of wheat and chickpea. It was concluded that chickpea yield reduced when intercropped with wheat. However, total productivity and land use efficiency were higher under the intercropping system as compared to mono-crops of other species. Wheat facilitated an increase in nodule number and dry weight and total productivity per unit area in chickpea when it was intercropped compared to when it was grown as a monocropping.

2.5. Effect on weed

Szumalgaski (2005) described the most important cause of weed suppression in intercropping system and stated that as intercrop capture more light than sole crop due to its different height and growing habit.

Banik *et al.* (2005) carried out an experiment on wheat - chickpea intercropping and monocropping. Row to row spacing was maintained 20 and 30cm. They observed the fact that intercropping resulted in increase in total productivity perunit area, improvement in land use efficiency and weed suppression.

Carr *et al.* (1995) reported that wheat and lentilintercropping resultedin reduction of weed biomass up to 96% in one year and 68% in another year than sole cropped lentil.

Bulson *et al.* (1997) conducted field trials on the effect of plant density on intercropped wheat and field bean and observed that weed biomass in intercrop was significantly reduced when seeding density of wheat and field bean was increased.

Eskandari and Ghanbari (2010) studied the impact of intercropping of wheat and bean on grain yield, dry matter production and weed biomass. They concluded that weed biomass was reduced in intercropping system as compared to wheat and bean sole crop.

Eskandari (2011) conducted field experiments on intercropping of wheat and faba bean and concluded that intercrop was more effective in weed suppression than wheat sole crop and he attributed this to less availability of environmental resources to weeds in intercropping system.

Szumigalski and Van (2005) observed that greater weed suppression in case of intercrop as compared to their sole crop when wheat-canola and wheat- canola-Pea were intercropped. This indicated some sort of synergism among crops with in intercrops regarding weed suppression.

2.6. Effect on pest and disease

Ma *et al.* (2007) studied strip cropping of wheat and Alfalfa to improve the biological control of wheat aphid (*Macrosiphumavenae*) by the mite (*Allothrombium ovatum*). They concluded that mean number of mites per parasitizedaphid was significantly more in strip cropping than in wheat monoculture.

Wang *et al.* (2008) studied to clarify the effect of intercropping of oil seedrape and garlic in winter wheat. They concluded thatpopulation density of *Sitobion avenae* was significantlydecreased in intercropping system than in sole crop.Elevated level of aphid parasitoids was observed in caseof wheat-oilseed rape intercropping field.

Bulson *et al.* (1997) described in an experiment that level of disease on wheat was low in wheat and field bean intercropping when bean density was increased.

Lennartsson (1988) observed in field trial that wheat and *Madicago lupulina* grown in mixture reduced the incidence of take all disease (*Gaeumannomyces graminis*) of wheat due to soil born pathogen.

Vilich-Meller (1992) noticed that there was reduction in incidence of leaf fungal diseases in case of mixture of winter rye with winter wheat.

2.7. Effect on erosion

Davidson (1994) described in an experiment that well managed strip intercropping system could result into greater soil and water conservation potential than most of the monocropping systems.

Chen *et al.* (2010) observed in field experiment that intercropping of wheat and potato grown in strips up to 5m can reduce wind erosion, soil desertification and degradation effectively.

2.8. Effect on quality

Lauk and Lauk (2005) concluded thatcompared to respective sole crop of cereal legume and cereal intercrop can result into higher grain and protein yield.

Hummel *et al.* (2009) conducted field experiments on canola/ wheat intercrop and they described that crop quality characteristics of canola have variable response to intercropping system.

Gooding *et al.* (2007) observed that intercropping wheat with grain legumes resulted in increase in N:S ratio upto 4% in wheat and there was also increased level of sodium dodecyl sulphate (SDS) and crude protein concentration (10 g kg^{-1}) inwheat.

Lithourgidis and Dordas (2010) concluded that intercropping of field bean with wheat improved forage dry matter, percentage of dry matter, crude protein, water soluble carbohydrates and neutral detergent fiber content compared with bean and wheat sole crop.

2.9. Effect on economic benefits

Subedi (1997) stated that intercropping of wheat and pea was profitable in terms of economic return as overall grain yield was maximized and recommended that sowing pea at rate of 30-45 kg ha^{-1} and wheat at rate of 120 kg ha^{-1} was more profitable.

Wasaya *et al.* (2013) stated that the maximum net income of Rs. 33647 ha^{-1} was obtained from wheat +3 rows of fenugreek against the minimum of Rs. 24791 ha^{-1} from sole cropping.

Khatun *et al.* (2001) described in an experiment that intercropping of potato with wheat grown with 2:5 gave higher LER, higher wheat equivalent yield, higher gross return and benefit cost ratio compared to 3:8 rows.

Khanzada *et al.* (2000) concluded that intercropping gave higher economic return than monoculture in case of wheat and safflower intercropped with alternate 4 row strips.

Verma *et al.* (1997) reported that maximum net return, benefit cost ratio and land equivalent ratio in case of intercropping of wheat and Indian mustard.

Singh *et al.* (2000) carried out field experiment to clarify the yield andeconomics of intercropping of wheat with potato. Theyobserved higher gross and net returns in wheat potatointercropping compared to sole wheat crop.

Nazir *et al.* (2002) noticed that intercropping combination ofsugarcane and wheat gave considerably higher netincome ha^{-1} than sole crop.

Padhi (2001) conducted a study at Kalimela (Orissa), on intercropping of Frenchbean (*Phaseolus vulgaris*), cowpea (*Vigna munguiculata*) and clusterbean (*Cymopsis tetragonoloba*) in maize with different row ratio (1:1, 2:1 and 2:2). Maize was sown at 60 cmapart in uniform rows and 45cm apart in paired rows, leaving 90 cm between 2 paired rows. In both the planting systems plant to plant distance of 25 cm within a row was maintained. Among them maize with French bean in 2:2 row ratio was superior in terms of monetary benefits over others.

Gollar and Patil (1997)observed in maize based cropping system that maize grain yields with cowpea, French bean, soybean and sunflower were 3421, 4544, 4024 and 2260 kg ha^{-1}, respectively, under staggered sowing and 4181,4935, 4539 and 3019 kg ha^{-1}, respectively, under simultaneous sowing. Maize with French bean intercropping recorded significantly higher maize yield than the sole crop (4491 kg ha^{-1}).

Munir *et al.* (2004) concluded that highest net income Rs. 10229 ha^{-1} with benefit cost ratio of 1.90 was observed in wheat when grown in 100cm spaced 4 rows of wheat and intercropping of 3 rows of gram.

Krishna and Raikhelkar (1997) studied in field experiment that in maize- legumes intercropping systemsfound that maize + blackgram (3.8t ha^{-1}), maize + green gram (3.6 t ha^{-1}) and maize + pegionpea (3.53 t ha^{-1}) gave significantly higher seed yield than other systems. Considering maize equivalent yield, maize + pegionpea (4.88 t ha^{1}) and maize + blackgram (4.66 t ha^{-1}), gave significantly higher equivalent yield than the other intercropping systems.

CHAPTER 3

MATERIALS AND METHODS

This chapter presenting a brief description of the experimental site, soil, climate, experimental design, treatments, cultural operations and analysis of different parameters for both BARI Gom-30 and BARI Sarisha-16 under the following headings;

3.1 Location

The experiment was carried out during the Rabi season (November to March) of 2015-16, at central farm of Sher-e-Bangla Agricultural University, Dhaka-1207. The experimental field was located at $90^0 22'$ E longitude and $23^0 41'$ N latitude at an altitude of 8.6 meters above the sea level. The experimental site was located under the Agro-ecological region of “Madhupur Tract” (AEZ No. 28).

3.2 Climate

The experimental area falls under the sub-tropical climate that is characterized by high temperature, high humidity and heavy rainfall with occasional gusty winds in the Kharif season (April-September) and less rainfall associated with moderately low temperature during the rabi season (October-March).

3.3 Soil

The farm belongs to the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. The land was above flood level and sufficient sunshine was available during the experimental period.

3.4 Crop planting material

3.4.1Description of BARI Gom-30:

BARI Gom-30 was developed by Wheat Research Centre, BARI in 2014. The variety is high yielding, early in maturity having good level of tolerance to terminal heat stress. The variety is resistant to stem rust (race Ug99) disease. It is resistant to leaf rust and tolerant to *Bipolaris* leaf blight disease. Grains are white amber in colour and medium in size (44-48g). Spikes are long with 45-50 average grains in each. Leaves are broad and recurved, Glaucosity is weak in spike and culm and medium in flag leaf sheath. Upper culm node hair is absent. Lower glume beak (LGB) lenhth is medium (5.1-12mm). LGB spicules-numerous, LGB shoulder medium and deeply elevated. Sowing time of this variety is November 15-30 and harvesting time is March-April. Crop duration is 100-105 days and yield potentiality is 4.5-5.5 t ha^{-1}. The variety is suitable for growing all over Bangladesh except of southern belt with salinity level more than 8 dS/M.

3.4.2 Description of BARI Sarisha-16:

BARI Sarisha-16 was released by Oilseed Research Centre, BARI in 2009. It is tall plant variety, silliquae are robust and each silliqua contains 9-11 seeds. Seed are brown in colour and bold and resistant to Orobanche. The variety is drought & salinity tolerant and suitable for late planting. Planting time is late October-late November and harvesting time is January-February.Crop duration is 105-115 and Seed yield of 1.9-2.25 t ha^{1}, Stover yield 3.60-4.0 t ha^{-1}. Suitable areas are Kustia, Jessore and Khulna.

3.5Experimental treatments

There were ten sets of treatments in the experiment which are shown below-

T_1: Sole wheat

T_2: Sole mustard

T_3: Wheat-mustard in 2:1 rows

T_4: Wheat-mustard in 3:1 rows

T_5: Wheat-mustard in 4:1 rows

T_6: Wheat-mustard in 5:1 rows

T_7: Wheat-mustard in 2:2 rows

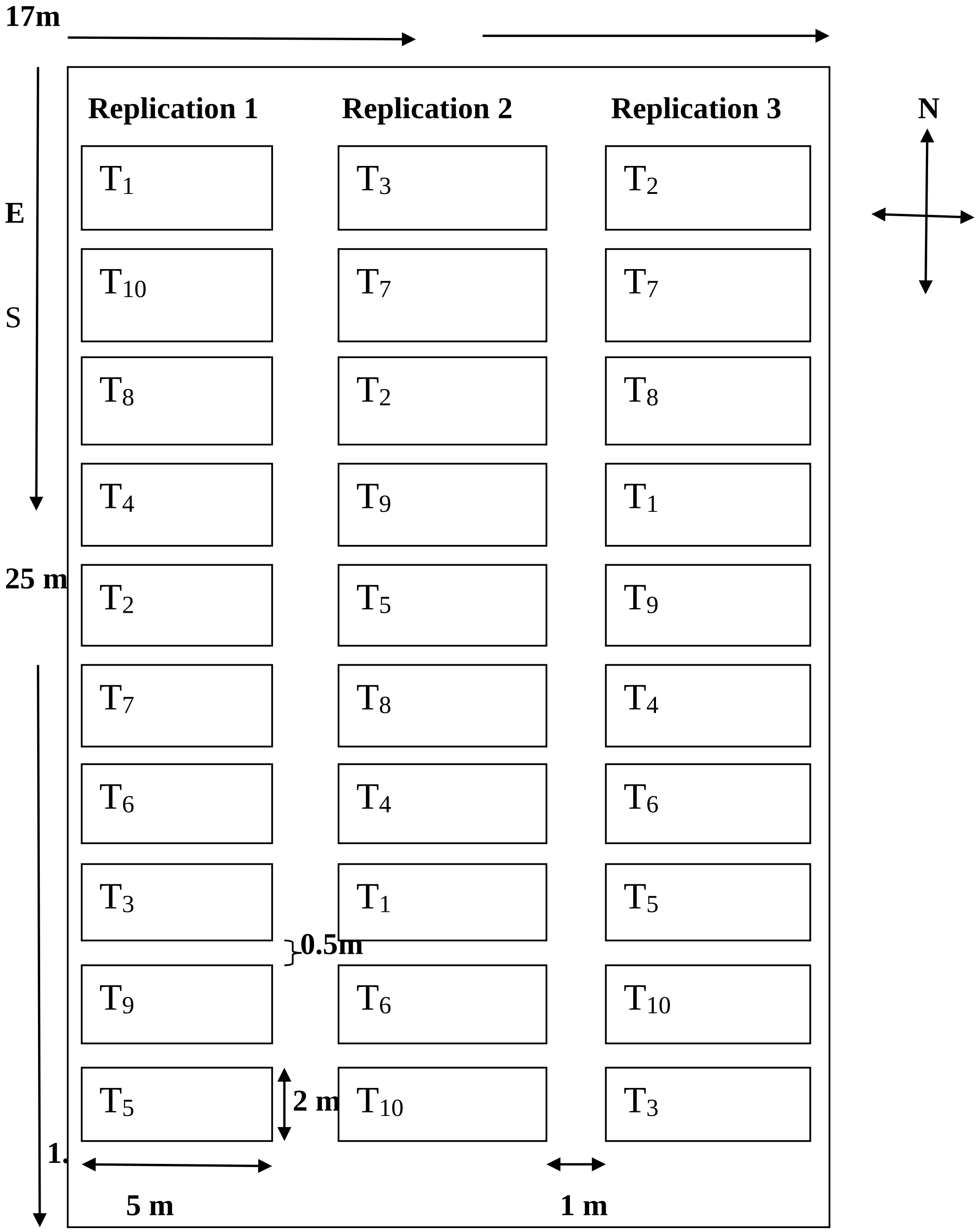
T_8: Wheat-mustard in 3:2 rows

T_9: Wheat-mustard in 4:2 rows

T_{10}: Wheat-mustard in 5:2 rows

3.6 Experimental design and layout

The experiment was conducted considering ten treatments and laid out in a Randomized Complete Block Design (RCBD). Each treatment was replicated three times. Field trials were conducted during the winter season in the research field of Agronomy Department, Sher-e-Bangla Agricultural University Campus. Mustard (BARI Sarisha-16) with wheat (BARI Gom-30) was selected for intercropping. Altogether 3 blocks were prepared and 3 replications for each category of sole wheat,sole mustard and wheat + mustard with different row ratios were cultivated for this experiment. The whole experimental area was 25 m x 17m. The distance between plots and blocks were 0.5 m and 1.0m respectively. Area of each plot was 5m x 2m = 10 m^2. Row to row distance for wheat and mustard was 20 cm and 30cm respectively.



T_1 : Sole wheat
T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

Figure 1. Layout of the experimental plot

3.7 Details of field operations

The cultural operations carried out during the experimentation are presented below:

3.7.1 Land preparation

The experimental field was first open on 21th November, 2015 with the help of a power tiller and prepared by three successive ploughings and cross-ploughings. Each plough was followed by laddering to have a desirable fine tilth. The visible larger clods were hammered to break into small pieces. All kinds of weeds and residues of previous crop were removed from the field. Sowing of wheat and mustard seed were made on 24 November 2015 according to design immediately after final land preparation. Individual plots were cleaned and finally leveled with the help of wooden plank.

3.7.2 Fertilizer application

The experimental field was fertilized with urea,triple super phosphate(TSP), muriate of potash(MoP) and gypsum at the rate of 220, 180, 50 and 120 kg ha^{-1} respectively.The whole amount of TSP, MoP, gypsum and one third of urea were mixed with soil at the time of final land preparation. The remaining urea was applied in two installments, at crown root initiation stage (20 days after sowing) and prior to spike initiation stage (55 days after sowing) as top dressing.

3.7.3 Collection and sowing of seeds

The wheat seeds (BARI Gom-30) were collected from Wheat Research Centre, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur. Furrows were made for sowing when the land was in proper joe condition. On 24th November, 2015 seeds were sown continuously with maintaining 20 cm row to row distance as per treatments. After sowing, seeds were covered with soil and slightly pressed by hand.

The mustard seeds (BARI Sarisha-16) were collected from Oilseed Research Centre, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur. At good tilth condition seeds were sown on 24th November, 2015. Furrows were made with hand rakes for sowing. Seeds were sown continuously in line as per treatments. The row to row distance was maintained at 30 cm. After sowing seeds were covered with soil and slightly pressed by hand.

3.7.4 Irrigation

The experimental plot was irrigated three times. The first, second and third irrigations were applied at crown root initiation stage, heading stage and grain filling stage respectively (20, 55, 70 days after sowing). Proper drainage system was maintained to remove the excess amount of water from the plot.

3.7.5 Pest management

Aphid infestation was occurred during the experiment, so malathion was spryed several times to control aphid. Special attentions were undertaken to protect the crop from the attack of parrots, pigeons and other birds.

3.7.6 Harvesting and sampling

The wheat crop was harvested at maturity on March 14, 2016. Plants were selected for samples from linear 50 cm area of each plot. The selected sample plants were then tagged and carried out for data collection carefully. Plants from central 4 m^2 was harvested separately plot-wise, bundled and tagged. The crop bundles were sun dried on the threshing floor. The grains and straw were separated by beating with the wooden stick and dried for constant moisture and the weight were recorded and converted into t ha^{-1} basis.

Five mustard plants were harvested on March 8, 2016 from where different data were collected. The mustard plants in harvested area was also bundled and carried to the threshing floor from where yield data were recorded.

3.8 Data recording

The following data were collected during the study period:

3.8.1 Data regarding different crop characters and yield of wheat

1. Plant height (cm) at different DAS
2. Number of tillers plant^{-1} at different DAS
3. Number of spikes plant^{-1}
4. Spike length
5. Number of florets spike^{-1}
6. Number of filled grains spike^{-1}
7. 1000-grain weight
8. Grain yield
9. Stover yield
10. Harvest index

3.8.2 Data regarding different crop characters and yield of mustard

1. Plant height (cm) at different DAS
2. Number of plants plot^{-1}
3. Number of main branches plant^{-1}
4. Number of siliquaeplant^{-1}
5. Siliqua length (cm)
6. Number of seeds siliqua^{-1}
7. 1000-seed weight
8. Seed yield
9. Stover yield
10. Biological yield
11. Harvest index

3.8.3 Data regarding weed

1. Weed population
2. Dry weight of weed biomass

3.9 Detailed data collection procedure of wheat

3.9.1 Plant height

The height of wheat plant was recorded in centimeter (cm) at 25, 50 and 75 days after sowing (DAS) and during harvest from the same pre-selected plants. To measure plant height five plants were selected from each plot and tagged. The height was measured from base of soil surface to tip and mean height was recorded.

3.9.2 Number of tillers plant^{-1}

The total number of tillers from selected area was counted. Data were recorded from the inner rows of each plot at the time of harvest.

3.9.3 Spike lengthplant^{-1}

The length of spike was measured by using a meter scale. The measurement was taken from base to tip of the spike. Average length of spike was taken from five selected spikes from inner rows plants of each plot. Data was recorded at harvest time. Mean data was expressed in centimeter (cm).

3.9.4 Number of florets spike^{-1}

Data on the total number of florets spike^{-1} was counted. Five spike bearing plants were selected and the average data were collected from the inner rows of each plot except harvest area during the time of harvest.

3.9.5 Number of filled grains spike^{-1}

The total number of filled grains spike^{-1} was counted. Average data were recorded from ten spikes bearing plants in each plot during the time of harvest.

3.9.6 Thousand-grain weight

Thousand seeds were counted from the seed sample and weighed at about 12% moisture level using an electric balance and recorded as per.

3.9.7 Grain yield

Each plot was harvested for recording yield data. After threshing, proper drying (12% moisture level) and cleaning, yield of each sample plot was weighed and values were converted to t ha^{-1}.

3.9.8 Stover yield

Each plot was harvested from which stover weight was determined after threshing and drying and finally converted them into t ha^{-1}.

3.9.9 Biological yield

Biological yield was calculated by the following formulae:

Biological yield = Grain yield + Straw yield

3.10Detailed data collection procedure of mustard

3.10.1 Plant height

Data was collected from five plants of each plot which selected randomly in the field.

3.10.2 Number of plants $plot^{-1}$

No. of plants $plot^{-1}$ were counted separately from each plot after uprooting mustard plant.

3.10.3 Number of main branches $plant^{-1}$

No. of main branches$plant^{-1}$were counted from selected plant $plot^{-1}$.

3.10.4 Number of siliquae $plant^{-1}$

Data was collected by counting siliquae number from five plants of each plot.

3.10.5 Length of siliqua (cm)

Ten siliqua were selected from five plants of each plot and measured by scale to collect data.

3.10.6 Number of seeds siliqua^{-1}

Seeds of ten siliquae collected from five plants of each plot were counted.

3.10.7 Thousand-seed weight

Thousand seeds were counted carefully and weighed at proper moisture level using an electrical balance and data was recorded.

3.10.8 Seed yield

Total mustard plants from harvested area of each plot were threshed and collected seeds were weighed by electric balance.

3.10.9 Stover yield

Stover weight was determined after threshing and sun drying of each plot separately and converted data to t ha^{-1}.

3.11 Detailed weed data

3.11.1 Weed population

Total weeds fromm^{-2}of each plot were uprooted and counted separately.

3.11.2 Dry weight of weed biomass

Weed biomass collected from each plot then oven dried at 80^{0}C until a constant weight was obtained. Then the sample was transferred into desiccators and allowed to cool down to the room temperature and final weight of weed biomass was taken.

3.12Harvest index

Harvest index (%) was determined by dividing the economic (grain) yield by the total biological yield (grain yield + straw yield) from the same area and multiplying by 100.

$$\text{Harvest index} = \frac{\text{Grain or seed yield (t ha}^{-1}\text{)}}{\text{Biological yield (t ha}^{-1}\text{)}} \times 100$$

3.13Assessment of yield advantage

3.13.1 Land equivalent ratio (LER)

The increase in productivity per unit area of mixed and intercrops was calculated in terms of land equivalent ratio (LER) using the following formula:

$$\text{LER} = \frac{\text{Intercrop yield of wheat}}{\text{Sole yield of wheat}} + \frac{\text{Intercrop yield of mustard}}{\text{Sole yield of mustard}}$$

3.13.2 Wheat equivalent yield

Wheat equivalent yield was computed by converting the yield ofcompanion crop (mustard) into the yield of main crop (wheat) on the basis of prevailing market price using the following formulae:

$$\text{Wheat equivalent yield} = Y_w + \frac{Y_i \times P_i}{P_w}$$

Where

Y_w = Grain yield of intercrop wheat

Y_i =Grain yield of intercrop mustard

P_i = Market price of mustard seed

P_w= Market price of wheat grain

3.13.3 Benefit cost ratio

The expenditure incurred on each treatment was worked out from the detailassessment of the fixed and variable cost involved such as land preparation, seed, plant protection, chemicals and labor engaged in different operations. Gross income for all treatment was calculated separately taking into consideration grain and straw yield of individual crop. Thereafter, net income was calculated after subtracting expenditure incurred on the individual treatment from the gross expenditure of the same treatment.

The benefitcost ratio was calculated as follows:

$$BCR = \frac{\text{Gross margin}}{\text{Cost of cultivation}}$$

3.13.4 Monetary advantage

Monetary advantage was used for economic performance of the mixed and intercrops. It was calculated using formula

$$\text{Monetary advantage} = GR \times \frac{LER - 1}{LER}$$

GR = Gross return and LER = Land equivalent ratio.

3.14Statistical analysis

The experiment was conducted following completely randomized block design. The collected data were analyzed by STAR software. The means for all recorded data were calculated and the analyses of variance of all characters were performed and the mean differences were evaluated.

CHAPTER 4
RESULTS AND DISCUSSION

The objective of this experiment was to determine the performance of wheat-mustard intercropping at different row ratios.Data on different growth and yield of wheat and mustard were recorded. The results have been presented and discussed with the help of table and graphs and possible interpretations are given under the following headings.

4.1 Effect of wheat-mustard intercropping on weed

4.1.1 Number of weeds m^{-2}

Weed population in each plot varied significantly for different row ratios of wheat and mustard intercropped (Appendix I). Weeds were collected from the field in early stage of wheat and mustard production. The highest weed population (84 and 80) was found in T_9 (four rows of wheat and two rows of mustard) and T_5 (four row wheat and one row mustard) respectively (Table 1). Medium weed population found in T_1 and T_4 respectively and others gave the lowest result which was statistically similar.

4.1.2 Dry weight of weeds

In case of dry weight, weed showed significant differences in wheat and mustard intercropping with different row ratios (Table 1 andAppendix I). The highest dry weight of weed (10.27 g) was found in T_9 (four rows wheat followed by two rows mustard) though it gave the highest weed population. The lowest dry weight of weed (1.32 g) was found in T_7 (two rows wheat with two rows mustard).

Table 1. Effect of wheat and mustard intercropping with different row ratios on weed population and dry weight of weed

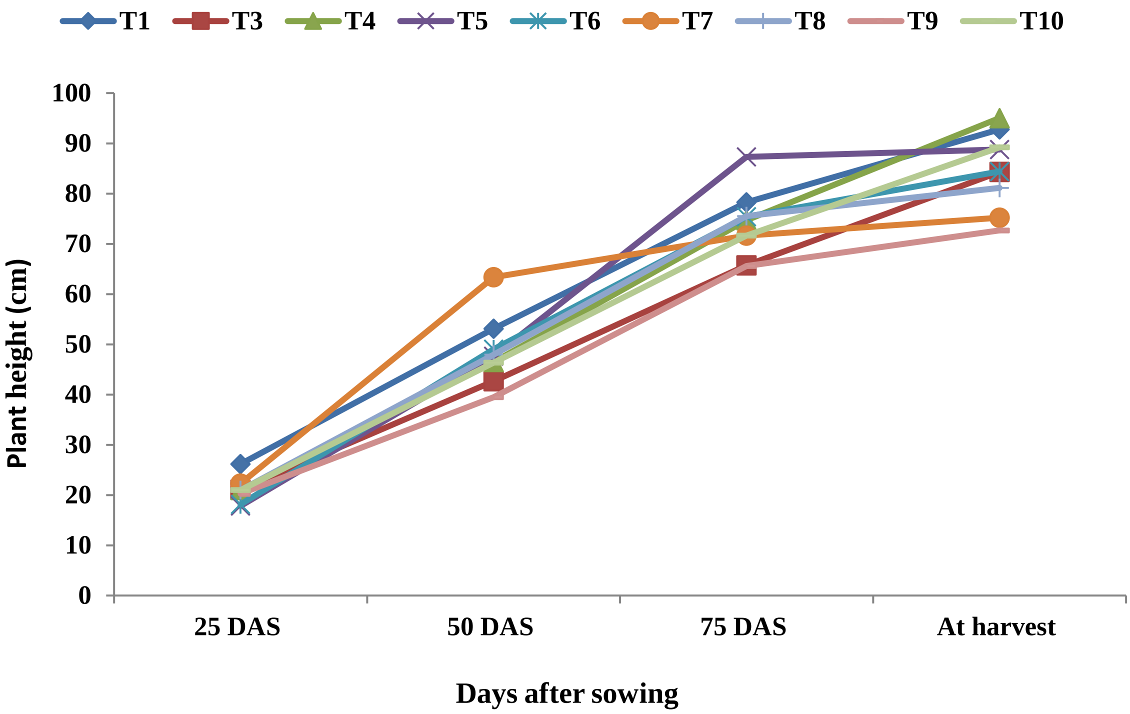
Treatment	No.of weedsm^{-2}	Dry weight(g)
T_1	64.00b	5.80c
T_2	42.67c	4.83cd
T_3	42.67c	3.52ef
T_4	65.33b	7.49b
T_5	80.00a	7.73b
T_6	38.67c	3.19ef
T_7	41.33c	1.32g
T_8	33.33c	2.24fg
T_9	84.00a	10.27a
T_{10}	57.33b	4.35de
LSD $_{(0.05)}$	14.66	1.31
CV (%)	9.11	8.8

T_1 : Sole wheat
T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

4.2 Crop characteristics of wheat

4.2.1 Plant height

Plant height of wheat was significantly influenced by different row ratios of wheat and mustard intercrop with the advancement of plant age (AppendixII). At 25 DAS there were less significant differences in plant height but it showed increasing trend with advancement of time up to 75 DAS and then slightly increased up to harvest. The tallest plant height was obtained from T_4 (95.03cm) and lowest plant height was obtained from T_9 (72.67cm) and T_7 (75.2cm) at harvest (Figure 2).

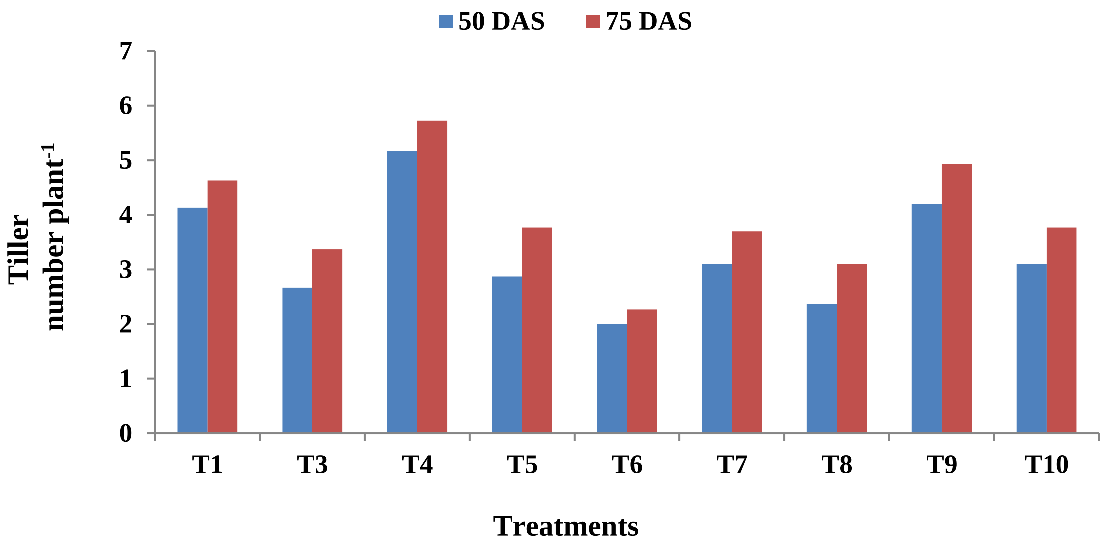


T_1 : Sole wheat
T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

Figure 2. Effect of wheat-mustard intercropping on plant height of wheat
[$LSD_{(0.05)}$ = 5.91, 4.47, 8.28 and 3.71 at 25, 50, 75 DAS and at harvest respectively]

4.2.2 Tiller number plant^{-1}

In intercropping with different row ratios, tiller number of wheat was significantly affected (Appendix III). Data collected from different days showed that the highest number of tiller was obtained from T_4 (three row wheat and one row mustard). The second height tiller number was obtained from sole wheat and T_9. The lowest tiller number was found from T_6 (five row wheat and one row mustard). This result was dissimilar to Singh *et al.*,(1995) who reported that the number of shoot or spike bearing tiller of wheat m^{-1} row length was the highest under pure stand and it decreasedsignificantly when the wheat was grown in any combination with Indian mustard.Mandal *et al.*,(1985) also reported wheat and mustard grown alone or in wheat combination with mustard that the number of ear-bearing tillers in wheat was highest when grown alone.



T_1 : Sole wheat
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5: Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9: Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

Figure 3. Effect of wheat-mustard intercropping on tiller no. of wheat
[$LSD_{(0.05)}$ = 0.72 and 0.61 at 50 and 75 DAS respectively]

4.2.3 Spike length plant^{-1}

There was significant variation observed on spike length for the effect of different wheat-mustard row ratios (Table 2 and Appendix IV). Treatment T_4 (three row wheat and one row mustard) was resulted maximum spike length (18.77cm) and T_7 (two rows of wheat with two rows mustard) resulted minimum spike length (13.95cm).

4.2.4 Number of florets spike^{-1}

Intercropping with different row ratios showed significant variations on number of florets spike^{-1} (Appendix IV). The experiment showed that the no. of florets was decreased with increasing mustard population. The highest no. of florets (71.67) were obtained from T_4 (three row wheat and one row mustard) and the lowest (36.67 and 35.33) from T_7 (two row wheat with two row mustard) and T_8 (three row wheat with two row mustard) respectively(Table 2).

4.2.5 Number of grains spike^{-1}

No. of grains spike^{-1}was showed significant differences on different row ratios on wheat-mustard intercroppingsystem (Appendix IV). Treatment T_4 (three row of wheat and one row of mustard) was resulted the highest no. of grains (54.33) spike^{-1}. The lowest no. of grains (28.33) was resulted by T_7 (two rows of wheat with two row mustard) and T_8 (three row wheat with two row mustard) (Table 2,).

Table 2. Effect of wheat and mustard intercropping with different row ratios on spike length, no. of floretsspike^{-1} and no. of grains spike^{-1} of wheat

Treatments	Spike length (cm)	No. of floretsspike^{-1}	No. of grains spike^{-1}
T_1	18.30ab	66.00b	45.33ab
T_3	14.94d-f	53.33cd	37.67bc
T_4	18.77a	71.67a	54.33a
T_5	16.11cd	46.33e	36.33bc
T_6	14.61ef	50.33de	38.67bc
T_7	13.95f	36.67f	28.33c
T_8	15.49de	35.33f	28.33c
T_9	17.17bc	57.33c	45.00ab
T_{10}	17.21bc	52.67cd	43.33ab
$LSD_{(0.05)}$	1.3	5.26	11.2
CV (%)	2.75	3.47	9.71

T_1 : Sole wheat
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5: Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9: Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

4.2.6 Thousand-grain weight plot^{-1}

Treatment T_4 (three row wheat and one row mustard) resulted the highest thousand-grain weight (42.8 g) similar to other treatments except T_5 (four row wheat with one row mustard) which showed the lowest thousand-grain weight (37.07 g) and also similar to others(Table 3 andAppendix V).

4.2.7 Grain yield

There was significant difference observed on grain yield of wheat for different row ratios in intercropping(Appendix V). The highest grain yield (3.4 tha^{-1}) was obtained from sole wheat and T_4 (three rows of wheat and one row mustard). The lowest grain yield (1.87 and 1.9 t ha^{-1}) were obtained from T_7 (two row wheat with two row mustard) and T_8 (three row wheat with two row mustard) respectively. It was observed that grain yield reduced with increasing mustard population (Table 3).

Table 3. Effect of wheat and mustard intercropping with different row ratios on 1000 seed weight, grain yield, stover yield, biological yield and harvest index of wheat

Treatments	1000 seed wt. (g)	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T_1	41.46ab	3.40a	3.17a	6.57a	51.74ab
T_3	40.12ab	2.63bc	2.63a-c	5.27bc	49.65ab
T_4	42.80a	3.40a	3.4a	6.80a	50.03ab
T_5	37.07b	2.47cd	2.1cd	4.57c-e	54.00ab
T_6	38.42ab	2.53bc	1.77d	4.30c-e	59.02a
T_7	40.35ab	1.87d	1.7d	3.57e	52.42ab
T_8	38.92ab	1.90d	2.07cd	3.97de	47.88b
T_9	38.27ab	3.10ab	2.9ab	6.00ab	51.89ab
T_{10}	40.32ab	2.60bc	2.13b-d	4.73cd	55.08ab
$LSD_{(0.05)}$	5.14	0.06	0.79	1.05	9.61
CV (%)	4.46	7.79	11.14	7.09	6.31

T_1 : Sole wheat
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

4.2.8 Stover yield

Stover yield showed statistically significant variation on wheat when intercropped with mustard(Table 3 andAppendix V). The highest stover yield (3.17 and 3.4 t ha^{-1}) were obtained from sole wheat and T_4 (three row wheat and one row mustard) respectively. Stover yield (1.77 and 1.7 t ha^{-1}) were the lowest and obtained from T_6 (five row wheat with one row mustard) and T_7 (two row wheat with two row mustard) respectively.

4.2.9 Biological yield

There was significant difference on biological yield of wheat (Table 3 and Appendix V). Treatment T_1 (sole wheat) and T_4 (three row wheat and one row mustard) resulted the highest biological yield respectively 6.57 and 6.8 t ha^{-1}. The lowest was recorded from T_7 (two row wheat with two row mustard) that was 3.57 t ha^{-1}.

4.2.10 Harvest index

Significant variation was observed on harvest index of wheat where T_6 (five row wheat with one row mustard) showed the highest (59.02%) and the lowest (47.88%) was recorded from T_8 (three row wheat with two row mustard) (Appendix VI). Other treatments showed similar effect on wheat (Table 3).

4.3 Crop characteristics of mustard

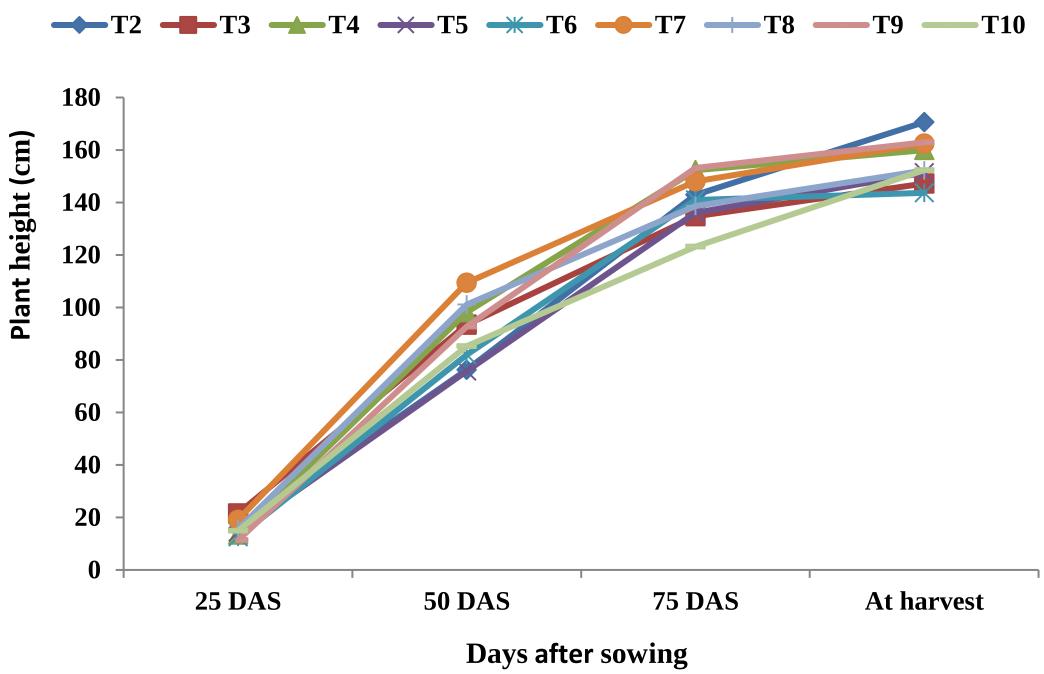
4.3.1 Plant height

Significant differences were observed on plant height in mustard when intercropped with wheat (Figure 4 and Appendix VII). At 25 DAS, the highest plant height (21.52cm) was found in T_3 (wheat two row with mustard one row) and the lowest (11.31 cm) in T_9 (wheat four row with mustard two rows).

At 50 DAS, the highest plant height (109.42cm) was obtained by T_7 (two row wheat with two rows mustard) and the lowest (75.76cm) at T_5 (four row wheat with one row mustard).

At 75 DAS, T_4 (three row wheat and one row mustard) resulted the highest plant height (152.33 cm) and the lowest (136.1 and 134.7cm) was found in T_5 (four row wheat with one row mustard) and T_3 (wheat two row with mustard one row) respectively.

At the end of harvest maximum plant height (170.6cm) was recorded by T_1 (sole crop) and minimum (143.67cm) by T_6 (five row wheat with one row mustard).

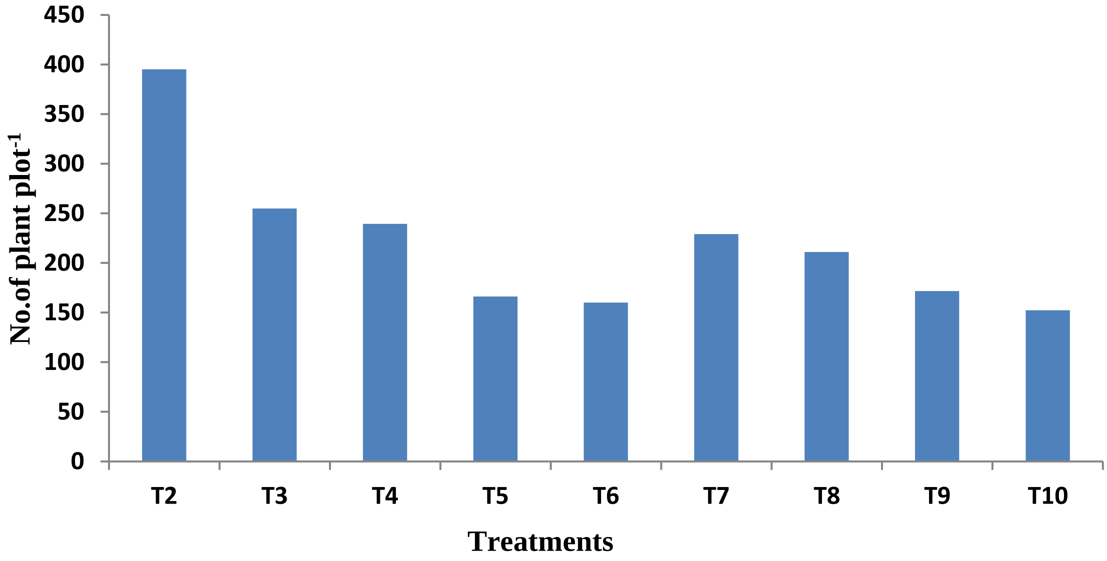


T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

Figure 4.Effect of wheat-mustard intercropping on plant height of mustard
[$LSD_{(0.05)}$ = 1.60, 15.15, 10.99 and 17.5 at 25, 50, 75 DAS and at harvest respectively

4.3.2 Number of plants plot^{-1}

There was significant variation between sole mustard and intercropped mustard in case of plant number plot^{-1} (Figure 5 andAppendix VIII). Sole mustard contained the highest no. of plant and other treatments showed no significant differences.



T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

Figure 5. Effect of intercropping of wheat and mustard on no. of plants plot^{-1} of mustard [$LSD_{(0.05)}$ = 134.18]

4.3.3 Numberof main branches plant^{-1}

Statistically significant variation was observed in no. of main branches plant^{-1} of mustard when intercropped with wheat(Appendix VIII). T_2 (sole mustard) recorded highest (6.77) no. of main branches plant^{-1} where T_9 (four row wheat with two row mustard) and T_{10} (five row wheat with two row mustard) showed the lowest (2.93 and 2.53) no. of main branches respectively (Table 4).

Table 4. Effect of wheat-mustard intercropping on no. of mainbranchesplant^{-1}, no. of siliquae plant^{-1} and no. of seeds siliqua^{-1}

Treatments	No. of main branches plant^{-1}	No .of siliquae plant^{-1}	No. of seeds siliqua^{-1}
T_2	6.77a	186.33a	15.00a
T_3	4.50d	94.33bc	7.67b
T_4	6.03b	123.33b	10.00b
T_5	4.17d	83.00cd	7.67b
T_6	5.17c	56.67d	6.67b
T_7	6.43ab	126.00b	9.67b
T_8	4.00d	119.67b	8.33b
T_9	2.93e	127.33b	10.00b
T_{10}	2.53e	116.67bc	7.33b
$LSD_{(0.05)}$	0.56	34.31	4.85
CV (%)	4.10	10.29	18.25

T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

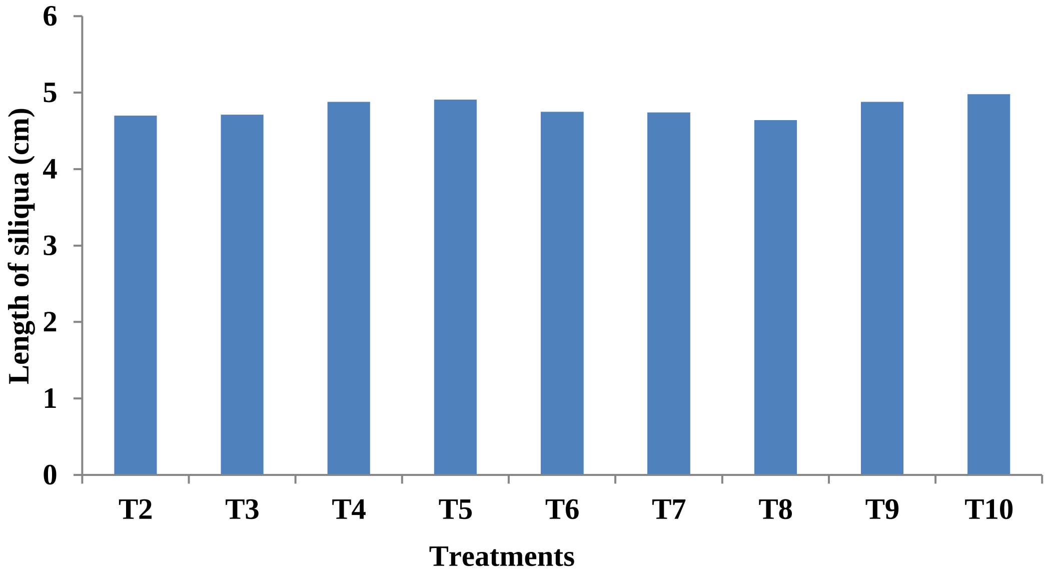
4.3.4 Number of siliquae plant^{-1}

Intercropping wheat with mustard showed significant effect on mustard (Table 4 andAppendix IX). The maximum number of siliquae plant^{-1} (186.33) was recorded from sole mustard and minimum (56.67) was given by treatment T_6 (five rows of wheat with one row mustard).

4.3.5 Length of siliqua

Intercropping wheat with mustard showed no significant differences on siliqua length of mustardthough the numerically maximum siliqua length (4.98 cm) was found in T_{10} (five rows of wheat two rows of mustard) and the minimum (4.64 cm) in T_8 (three rows of wheat with two rows of mustard) (Appendix IX).

Sharma *et al.*,(1986) conducted an experiment during winter season on a sandy clay loam soil of Pantnagar. Treatments comprised of seed mixture of wheat andmustard in 1:1, 2:1, 3:1, 5:1; one row of wheat alternated with one mustard row; 4, 6 and 10 wheat rows alternated with 2 rows of mustard as well as pure wheat and mustard. It was observed thatsiliquae plant^{-1} of mustard remained unaffected in intercropping.



T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

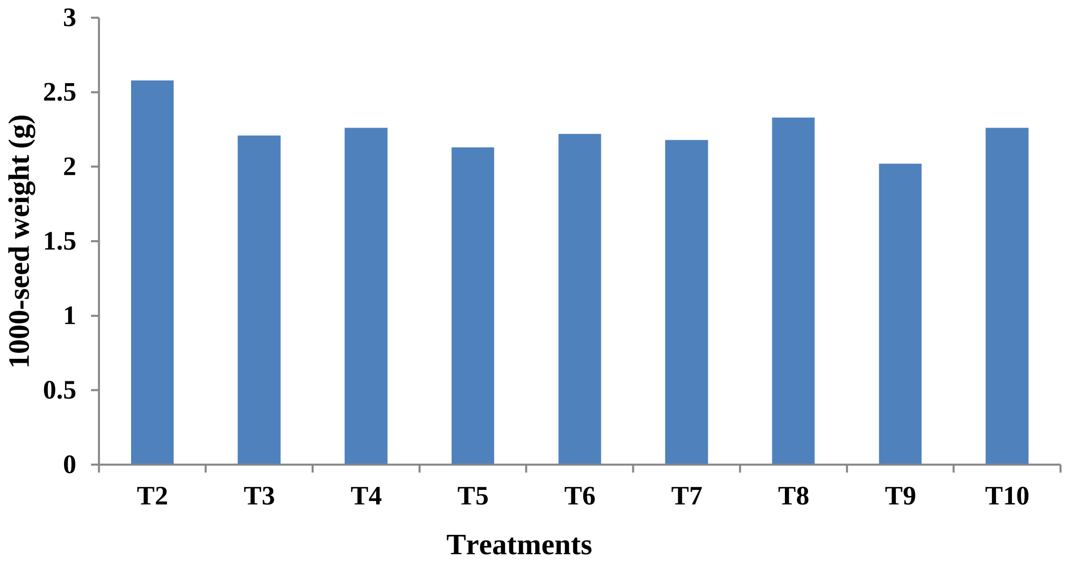
Figure 6. Effect of intercropping of wheat and mustard on length of siliqua ofmustard

4.3.6 Number of seeds siliqua^{-1}

Treatment T_2 (sole mustard) was resulted the highest (15) no. of seeds siliquae^{-1} where other treatments showed more or less same result and the lowest (6.67) was recorded from T_6 (five row wheat with one row mustard) (Table 4 andAppendix IX).

4.3.7 Thousand-seed weight

There was no significant variation in thousand-seed weight of mustard observed when intercropped with wheat (Figure 7 andAppendix X).Sharma *et al.*,(1986) conducted an experiment of intercropping mustard with wheat during winter season on a sandy clay loam soil of Pantnagar and observed that 1000-seed weight of mustard remain unaffected.



T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

Figure 7. Effect of wheat-mustard intercropping on thousand-seed weight of mustard

4.3.8 Seed yield of mustard

Seed yield of mustard resulted significant differences when intercropped with wheat(Appendix X). Sole mustard was resulted the highest seed yield (1.02 t ha^{-1}) because of large area and population while among other treatments T_6 (five row wheat with one row of mustard) resulted the lowest (0.13 t ha^{-1}) seed yield (Table 5).

Table 5. Effect ofwheat and mustard intercropping with different row ratios seed yield, stover yield, biological yield and harvest index of mustard

Treatments	Seed yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	Harvest index
T_2	1.02a	4.99a	6.02a	17.85ab
T_3	0.33bc	2.55bc	2.88bc	12.98bc
T_4	0.46b	1.84bc	2.3bc	22.29a
T_5	0.18de	1.95bc	2.13bc	8.52c
T_6	0.13e	1.48c	1.61c	9.59bc
T_7	0.29cd	3.17b	3.46b	9.6bc
T_8	0.32b-d	2.52bc	2.84bc	12.36bc
T_9	0.31cd	2.02bc	2.33bc	13.65a-c
T_{10}	0.24c-e	2.03bc	2.27bc	11.21bc
$LSD_{(0.05)}$	0.15	1.51	1.49	8.84
CV (%)	13.82	20.79	17.87	23.19

T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:1 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

4.3.9 Stover yield

Significant difference was observed on stover yield of mustard in different treatments (Table 5 and Appendix X). Plant population was higher in sole mustard hence it was resulted maximum (4.99 t ha^{-1}) stover yield and minimum (1.48 t ha^{-1}) was obtained from intercropped mustard T_6 (five row wheat with one row mustard).

4.3.10 Biological yield

There was significant differences observed in biological yield of mustard where the highest (6.02 t ha^{-1}) was obtained from T_1 (sole mustard) and the lowest (1.61 t ha^{-1}) from T_6 (five row wheat with one row mustard) when intercropped with wheat. However there was less difference among other treatments (Table 5 andAppendix X).

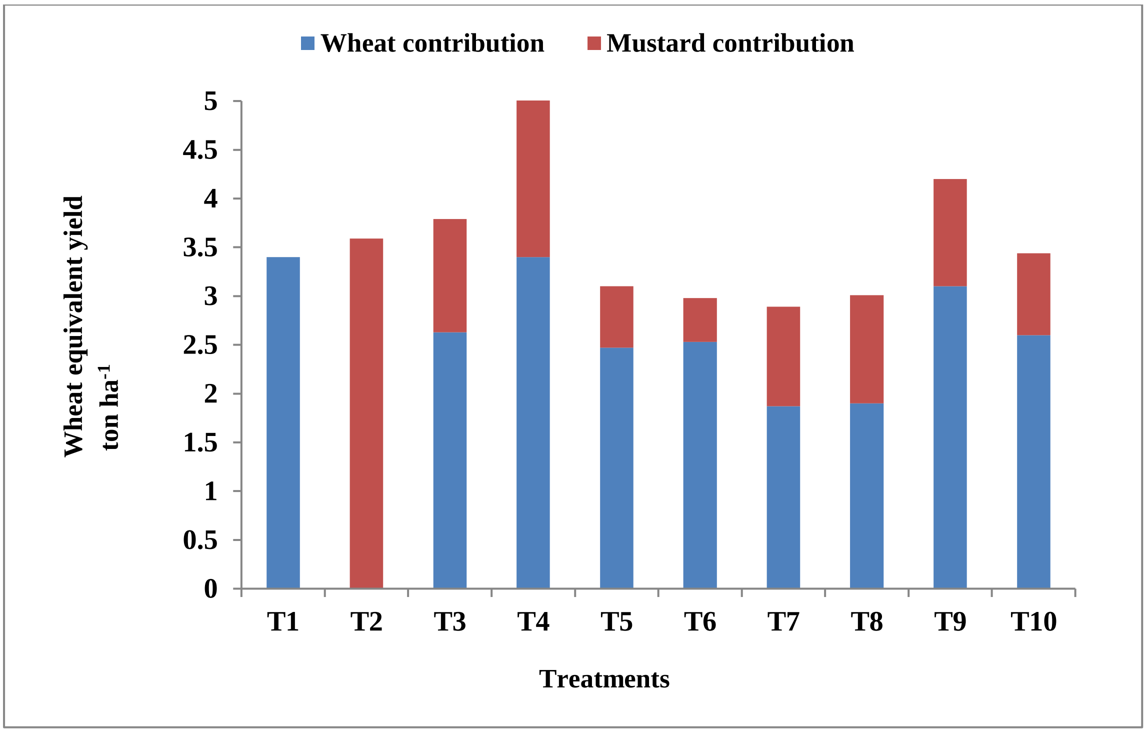
4.3.11 Harvest index

The highest (22.29%) harvest index of mustard was given by T_4 (three wheat row with one mustard) and lowest (8.52%) was obtained from T_5 (four wheat row and one mustard row) (Table 5 andAppendix X).

4.4Productivity performance

4.4.1 Wheat equivalent yield

The wheat equivalent yield was significantly affected by wheat-mustard intercropping. (Figure 8 andAppendix VI) The highest wheat equivalent yield (5.03 t ha^{-1}) was obtained from T_4 (three row wheat and one row mustard).The highest equivalent yield was attributed to the higher price of mustard seed.



T_1 : Sole wheat
T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:2 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

Figure 8. Effect of intercropping of wheat and mustard on wheat equivalent yield[$LSD_{(0.05)}$ = 0.85]

4.4.2 Land equivalent ratio

In wheat and mustard intercropped different result was found in land equivalent ratio for different treatments (Table 6). Treatment T_4 (three wheat row with one mustard) showed highest (1.45) land equivalent ratio. Cultivable land in the whole world is decreasing day by day and sole crop needs more land than intercropped. So, intercropped can served in an advantage by proper land utilization. Verma *et al.,* (1997) also reported that maximum land equivalent ratio in case of intercropping of wheat and Indian mustard.

4.5 Economic analysis

4.5.1 Gross income

The gross return in wheat and mustard intercropping under different rowratios shown in (Table 6). It was found that the intercropping treatments always gave better gross return than the sole crops. So, it was clear that in the intercropping treatments with proper row ratios the gross return was better than the sole cropping practices. The highest gross return (120250Tk.ha^{-1}) was obtained from the T_4 (three row wheat followed by one row mustard).

Table 6. Effect of wheat-mustard intercropping on LER and economic Productivity

Treatments	Gross income (Tk. ha^{-1})	Net income (Tk. ha^{-1})	LER	Monetary advantage (Tk.)	BCR
T_1	79887.5	29395.5	1.00	-	1.58
T_2	75017.6	19657.1	1.00	-	1.35
T_3	95225.0	36153	1.09	7862.61(+)	1.61
T_4	120250.0	61178	1.45	37318.97(+)	2.04
T_5	77187.5	18115.5	0.90	8386.23(-)	1.31
T_6	71787.5	12715.5	0.87	10537(-)	1.22
T_7	76062.5	16990.5	0.83	15139.54(-)	1.29
T_8	77412.5	18340.5	0.87	11261.61(-)	1.31
T_9	102450.0	43378.0	1.22	18474.59(+)	1.73
T_{10}	84400.0	25328.0	1.00	-	1.43

T_1 : Sole wheat
T_2 : Sole mustard
T_3 : Wheat-mustard in 2:1 rows
T_4 : Wheat-mustard in 3:1 rows
T_5 : Wheat-mustard in 4:1 rows
T_6 : Wheat-mustard in 5:2 rows
T_7 : Wheat-mustard in 2:2 rows
T_8 : Wheat-mustard in 3:2 rows
T_9 : Wheat-mustard in 4:2 rows
T_{10} : Wheat-mustard in 5:2 rows

4.5.2 Net income

Net return over variable cost was found encouraging in the intercropping treatments with proper row ratios. Out of different intercropped treatments the highest net return (61178 Tk. ha^{-1}) was found in T_4 (three row wheat intercropped with one row mustard). It was also found that intercrop always did not give the highest net income if it was not planted proper row ratios(Table 6).

4.5.3 Benefit cost ratio

When benefit-cost ratio of each treatment was examined it was found that the treatment of T_4 (three row wheat intercropped with one row mustard) gave the highest benefit-cost ratio (2.04) followed by T_9 (four row wheat intercropped with two row mustard), T_3 (two row wheat intercropped with one row mustard). The lowest benefit-cost ratio (1.22) was obtained from the T_6 (five row wheat with one row mustard) which also gave the lowest net return (Table 6).

CHAPTER 5

SUMMARY AND CONCLUSION

An experiment was undertaken at the research field of the Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka from November, 2015 to March, 2016 to evaluate the performance of wheat-mustard intercropping as influenced by row ratios.

In this experiment ten treatments were included such as T_1 (sole wheat), T_2 (sole mustard), T_3 (wheat-mustard in 2:1 rows), T_4 (wheat-mustard in 3:1 rows), T_5 (wheat-mustard in 4:1 rows), T_6 (wheat-mustard in 5:1 rows), T_7 (wheat-mustard in 2:2 rows), T_8 (wheat-mustard in 3:2 rows), T_9 (wheat-mustard in 4:2 rows) and T_{10} (wheat-mustard in 5:2 rows). Seeds of wheat and mustard were sown in line at the field. The sowing date of wheat and mustard was 24th November, 2015. The unit plot size was 5m x 2m = 10m^2.Observations were made on wheat as weed population, dry weight of weed, plant height,number of tillers plant^{-1}, spike length, weight of 1000-grain, no. of grains spike^{-1}, grain yield, stover yield, biological yield and harvest index.

Treatment T_4 (wheat-mustard in 3:1 rows) showed the highest result in case of plant height, tiller number plant^{-1}, spike length, no. of floretsspike^{-1}, no. of filled grains spike^{-1}, thousand-seed weight, grain yield (t ha^{-1}) and stover yield (t ha^{-1}) which was mostly similar to sole wheat. Seed yield of wheat was significantly decreased with increasing number of mustard. The highest seed yield (3.4 t ha^{-1}) was obtained from T_1 (sole wheat) and T_3 (wheat-mustard in 2:1 rows). The lower seed yield (1.9 and 1.87 t ha^{-1}) was found in T_8 (wheat-mustard in 3:2 rows)and T_7 (wheat-mustard in 2:2 rows) respectively. Seed yield of mustard was significantly affected by wheat-mustard intercropping system. The highest seed yield (1.02 t ha^{-1}) was obtained from T_2 (sole mustard). In intercropping the highest seed yield (0.46 t ha^{-1}) was found from T_4 (wheat-mustard in 3:1 rows) and the lowest (0.13 t ha^{-1}) was found from T_6 (wheat-mustard in 5:1 rows).

The intercropping system was evaluated on the basis of wheat equivalent yield, land equivalent ratio (LER) and BCR. The highest wheat equivalent yield (5.03 t ha^{-1}) was obtained from T_4 (wheat-mustard in 3:1 rows). The highest equivalent yield was attributed to the highest price of mustard. Treatment T_4 (wheat-mustard in 3:1 rows) showed the highest LER that was higher than sole wheat. Economic analysis of the different treatments showed that the highest gross return (120250 $Tk.ha^{-1}$) and the highest net return (61178 $Tk.ha^{-1}$) and BCR (2.04) were found in T_4 (wheat-mustard in 3:1 rows).

From the findings of the present experiment, it may be concluded that intercropping of wheat and mustard with three rows of wheat and one row of mustard was the most compatible and this gave the higher combined yield, wheat equivalent yield, net return, LER and BCR over normal planting of wheat.

Therefore, the result of intercropping can be changed depends on geographical location, field environment, density of pest and disease, water supply etc. So, more study on wider range of intercropping effect on wheat and mustard cultivation should be done over different Agro-ecological zones to reach a specific recommendation.

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APPENDICES

Appendix I. Mean square values for No. of weeds m^{-2} and dry weight of weeds

Source of variation	Degrees of freedom	Mean square values for	
		No. of weeds m^{-2}	dry weight of weeds
Replication	2	19.7333	0.1289
Treatment	9	962.1333**	23.0358**
Error	18	25.0667	0.1992

** = Significant at 1% * = Significant at 5%

Appendix II. Mean square values for plant height of wheat

Source of variation	Degrees of freedom	Mean square values for plant height at			
		25 DAS	50 DAS	75 DAS	At harvest
Replication	2	0.0132	0.5411	8.0933	0.5137
Treatment	8	17.7345**	137.3411**	131.6342**	171.1904**
Error	16	4.1356	2.3726	8.1354	1.6341

** = Significant at 1% * = Significant at 5%

Appendix III. Mean square values for tiller number of wheat

Source of variation	Degrees of freedom	Mean square values for tiller no. at	
		50 DAS	75 DAS
Replication	2	0.0811	0.0515
Treatment	8	3.0817**	3.2368**
Error	16	0.0607	0.044

** = Significant at 1% * = Significant at 5%

Appendix IV. Mean square valuesfor spike length, no. of florets spike^{-1} and no. of grains spike^{-1} of wheat

Source of variation	Degrees of freedom	Mean square values for		
		Spike length	No. of florets spike^{-1}	No. of grains spike^{-1}
Replication	2	0.3017	5.4815	1.8148
Treatment	8	8.4658**	435.3426**	210.787**
Error	16	0.201	3.2731	14.8565

** = Significant at 1%   * = Significant at 5%

Appendix V. Mean square values for thousand-grain yield, grain yield (t ha^{-1}), stover yield (t ha^{-1}) and biological yield (t ha^{-1}) of wheat

Source of variation	Degrees of freedom	Mean square values for			
		1000-grain wt.	Grain yield	Stover yield	Biological yield
Replication	2	2.0584	0.1411	0.0104	0.0804
Treatment	8	8.9704*	0.9575**	1.1429**	3.9643**
Error	16	3.1356	0.0428	0.0733	0.13

** = Significant at 1%   * = Significant at 5%

Appendix VI. Mean square values for wheat equivalent yield and harvest index of wheat

Source of variation	Degrees of freedom	Mean square values for	
		Wheat equivalent yield	Harvest index
Replication	2	0.0606	12.0157
Treatment	8	1.3171**	32.9138*
Error	16	0.0848	10.9553

** = Significant at 1%   * = Significant at 5%

Appendix VII. Mean square values for plant height of mustard

Source of variation	Degrees of freedom	Mean square values for plant height at			
		25 DAS	50 DAS	75 DAS	At harvest
Replication	2	1.3772	43.7537	17.6993	15.0044
Treatment	8	30.5242**	399.549**	268.3901**	223.7467**
Error	16	0.3045	27.2302	14.3126	36.2778

** = Significant at 1% * = Significant at 5%

Appendix VIII. Mean square values for no. of plant plot^{-1} and no. of branches plant^{-1} of mustard

Source of variation	Degrees of freedom	Mean square values for	
		No. of plant plot^{-1}	No. of branches plant^{-1} of mustard
Replication	2	3233.333	0.1226
Treatment	8	17211.5833**	6.7106**
Error	16	2133.917	0.0376

** = Significant at 1% * = Significant at 5%

Appendix IX.Mean square values for length of siliqua, no. of siliquaen plant^{-1} and no. of seeds siliquae^{-1} of mustard

Source of variation	Degrees of freedom	Mean square values for		
		Length of siliqua	No.of siliquaeplant^{-1}	No. of seeds siliquae^{-1}
Replication	2	0.0255	95.8148	3.7037
Treatment	8	0.0399	3865.9259**	18.9259**
Error	16	0.1504	139.5648	2.787

** = Significant at 1% * = Significant at 5%

Appendix X. Mean square values for thousand-seed weight, seed yield (t ha^{-1}), stover yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index of mustard

Source of variation	Degrees of freedom	Mean square values for				
		Thousand-seed weight	Seed yield	Stover yield	Biological yield	Harvest index
Replication	2	0.5276	0.0011	5.8524	5.9412	156.7157
Treatment	8	0.0706	0.2112**	3.328**	5.0042**	58.903**
Error	16	0.0728	0.0026	0.2714	0.2635	9.2528

** = Significant at 1%   * = Significant at 5%