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EFFECT OF LEGUME TYPE, NITROGEN DOSE AND AIR QUALITY ON BIOMASS AND BIOETHANOL PRODUCTION IN SWEET SORGHUM-LEGUME INTERCROPPING

SUMMARY

Sweet sorghum is grown as a sole and potential energy crop in water limited areas. It has inherent potential to be intercropped with legumes for the production of both food and bioethanol. To explore this potential, several intercropping patterns composed of two legumes (viz. mungbean and soybean), three nitrogen doses (viz. 30, 60 & 120 kg ha^{-1}) and two air quality environments (viz. filtered air & ambient air) with three sole crops (sweet sorghum, mungbean and soybean), in a completely randomized design with three replicates in dry season were studied. Dry matter (DM), grain, above ground biomass (AGB), and calculated bioethanol (BEY) yields of sweet sorghum and legumes in sole and intercropping stands and within intercropping were compared. The DM, grain yield and AGB of sweet sorghum were significantly ($p \leq 0.001$) reduced when intercropped with mungbean (36.2, 4.5 & 40.7 t ha^{-1}, respectively) but remained at par ($p > 0.05$) in intercropping with soybean (40.3, 5.2 & 45.5 t ha^{-1}, respectively) compared to sole crop of sweet sorghum (41.8, 5.1 & 46.9 t ha^{-1}, respectively). Nitrogen treatment of 60 kg ha^{-1} produced optimized DM, grain/seed, AGB, and BEY compared to other N levels. Influence of ambient air (polluted) on sweet sorghum crop was not significant ($p > 0.05$); however filtered air significantly ($p \leq 0.05$) improved the dry matter and seed yields in intercropped legumes. Establishing sweet sorghum with mungbean or with soybean in simultaneous seeding and provided with 60 kg ha^{-1} of N under filtering of air pollutants enhanced the performance of legume, crop yields and bioethanol production.

Keywords: Air Pollutants, Bioethanol, Dry matter, Intercropping, Nitrogen, Legumes, Sweet Sorghum

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INTRODUCTION

Crop biomass is a key player among the renewable sources of energy to curb ongoing adverse environmental changes emerging mainly from escalated petroleum fuel usage around the globe. The time and land have always been a constraint in already food scarce world and the bio-fuel production can further shrink it to a alarming extent when exploring a pure biomass based bio-fuel system. However, availability of plant biomass with appropriate quantity and quality without competing with food crops has been a prime significance. Biomass from natural sources has always been an abundant source on earth, but a domesticated system composed of food and energy crops can play a key role to meet up the future food and bio-fuel demands. Hence an optimized system with appropriate agronomic practices ensuring negligible competition between food and fuel and promising sustainability under changing climatic conditions is direly needed.

Bio-fuel has been given an extended interest due to environmental benefits and to reduce import expenditures on energy, whereby crop biomass has been considered a key renewable source for bioethanol production in many countries. In this aspects, corn in the USA (Ellyson, 2011), sugarcane in Brazil (Almeida, 2007), cassava, sugarcane molasses and sweet sorghum in Thailand and China (Praiwan, 2010) are recommended crops as feedstock for bioethanol production to replace petroleum fuel maximally (Rajvanshi *et al*, 1989). Different sources have been considered for bioethanol production in different regions around the globe, but most of such sources were found to be less effective due to changing climatic conditions, water shortages, life cycle of such species, and competition with the food industry.

Intercropping is a system of growing two or more crops together simultaneously (Andrews and Kassam, 1976). It can accommodate diverse species of the crops capable of mutual cooperation or partial cooperation. This would be an ideal system to support the production of both food and energy crops at the same time. But the competition between component crops with concomitant reduction in their biomass yield together with changes in biofuel yielding chemical composition is likely to occur as a limitation in due to space and radiation interference. Hence, intercropping as a system for biomass production needs to be assessed with suitable agronomic practices while taking the environmental concerns into account, i.e. air pollution. In turn, assessment for the ongoing dynamics in environmental parameters on growth and yield of agricultural crops is direly needed to take necessary steps to optimize the concerned activities. Cereal-legume intercropping not only improves the total productivity per unit area of land but may also improve the quality of the mixed output (Patel & Rajagopal, 2001).

Limitation of nutrients in cropping system results into reduced food production whereas over fertilization create environmental issues like air pollution (Pedersen, 2003). Therefore, balanced use of fertilizer can help improve the grain yield and maintain its nutritive value (Chela *et al*, 1993). Increasing air pollution mainly due to rapid expansion of human population associated with greater demands for energy, industry and traffic has detrimentally affected the growth and yield of agricultural crops (Nghiem and Oanh, 2006). Increasing urbanization due to human development resulted in reduced distances between agricultural lands and urban and peri-urban industrial emission sources (Wahid *et al*, 1995). Ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are the main air pollutants having direct influence on plants (Emberson *et al*, 2009) and cause visible (discoloration) and invisible (physiological or biochemical) changes when concentration increased to sensitive levels (Ashmore and Marshall, 1999). Sulfur dioxide, O_3 and NO_2 in combinations result in synergistic effects on plants (Clag, 1996).

Merits of cereal-legume intercropping compared to sole cropping have been well understood. However, the role of sweet sorghum in intercropping for biomass production is important under changing climatic conditions. Whereas, compatibility of sweet sorghum with legumes for intercropping under different levels of N and air quality have not been studied. The current research includes the observations and comparison of biomass yield for bioethanol production as influenced by different agronomic practices and environmental parameters for sweet sorghum-based sole and intercropping systems.

MATERIAL AND METHODS

Treatments and Experimental management. This study was conducted at the Agricultural Systems and Engineering Research Farm, Asian Institute of Technology (AIT), Thailand, during the dry period of 2011. The site was located at latitudes of 13° 44' N, longitude of 100° 30' E in the Central Plain of Thailand. The soil is acid sulfate soil, and belongs to Ongkarak clay (very fine texture, mixed acid, isohyper, sulfic tropaquepts) hydromorphic alluvial in the Rangsit Series (Cheyglinted, 2000). Before the start of experiment land was fallow and covered with a uniform mix stand of few grass species. Twelve treatments composed of 2 × 3 × 2 factorial combinations of two intercropping associations (viz. sweet sorghum and mung bean or soybean), three N levels (viz. 30, 60, 120 kg ha^{-1}) and two air quality levels [viz. charcoal filtered air & ambient air], and three sole crops of sweet sorghum, mung bean and soybean in a complete randomized design tested together with three replications.

Recommended varieties of sweet sorghum (KKU-40) (Laopaiboon *et al*, 2009), mung bean (Chinat-72 – determinate type) (Khajudparn, 2007) and soybean (Nakhorn Swan 1 – indeterminate type) (Chotiyarnwong, 2007) cultivated in Thailand were chosen for the study. Land was prepared using disc harrow, rotary tiller and a plank, and plots were arranged as raised beds. Plot size was 4 m × 4 m while inter plot space was maintained as 1.5 m. All crops were seeded at the same time on 2nd January, 2011. Crop rows were arranged in east-west directions. Sole crops of sweet sorghum, mungbean and soybean were sown in 45 cm rows and with intra row spacing was maintained as 15, 10 and 20 cm, respectively. In intercropping sweet sorghum was sown at 45 cm and legume in the middle of two sweet sorghum rows. The plant densities of sweet sorghum, mungbean and soybean were 11,111; 222,222 and 148,148 plants ha^{-1} maintained in both intercropping and sole crops. The respective intercropping plots were provided with three rates of N as 30, 60 and 120 kg ha^{-1} as per treatment. Sole cropped sweet sorghum was supplied 60 kg N, 20 kg P and 20 kg K ha^{-1} and total P and K were applied at sowing. The dose of N was divided into two splits and 50 % applied at sowing and the rest at booting for sole cropped sweet sorghum. For both sole crops of mungbean and soybean, N and P were provided at the rate of 30 and 20 kg ha^{-1}, respectively, at seeding.

Plots were irrigated daily by sprinkler irrigation system until seedling emergence, after which plots were irrigated every alternate day according to estimated reference evapotranspiration (ETo) and growth stage specific crop coefficient (Kc). Weeds were manually uprooted at 5, 10 and 15 days after sowing. Carbofuran granules (2%) (2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl methylcarbamate), carbaryl (1-naphthyl-methylcarbamate) and Melathion (Dimethoxy phosphino thioyl thio butanedioic acid diethyl ester) were used at the rate of 50 and 0.28 kg ha^{-1} and 0.5 L ha^{-1}, respectively, for all plots in order to control shoot fly and aphids.

Air quality management and Sampling. Eighteen open top chambers with two-meter diameter and two meter height were built in randomly selected plots using bamboo, iron rods and thin plastic sheets for filtered air supply. Two improvised carbon filters were connected to each chamber using thick-walled plastic tubes with a uniform length in order to maintain even distribution of filtered air among chambers. The air was filtered using ground charcoal, for which filters were improvised using a 60cm long pvc pipe and locally available ground charcoal. The filtered air was continuously supplied from 9.00 am to 4.00 pm throughout the study period with an air pump (PUMA, model: XM-2525) of output 200 L min^{-1} (3 hp, 10 kg psi^{-1}) to remove air pollutants (O_3, NO_2 and SO_2) from chambers. In addition, air sampling was adapted from 9.00 a.m. to 12.00 noon and from 1.00 p.m. to 4.00 p.m. commencing from two weeks after seeding and continued fortnightly until 12 weeks.

Sampling units were prepared using four 100 ml plastic bottles, a small air pump (BOYU, model: SC-3500) having output of 2.5 L min^{-1} (0.012 MPa) and plastic tubing. A separate power line was set up for every plot with a single switch to control time duration of air sampling uniform. The plastic bottles contained the specific absorbent solutions as per pollutant expected (i.e. O_3, NO_2 and SO_2 analysis) together with control, distilled water. Following the absorption for three hours, solutions were transferred to laboratory and stored in refrigerator at 0 ^{0}C. Respective solutions were used for analysis for O_3, NO_2 and SO_2 as per methods described by Radojevic and Bashkin (1999) and also by Saltzman and Gilbert (1959) for ozone and Abeyrante and Ileperuma (2006) for sulfur dioxide and nitrogen dioxide.

Plant sampling and measurement. Plants were sampled for dry matter and yield related observations. At physiological maturity, dry matter and grain yield in sweet sorghum were recorded by removing plants from two adjacent rows each of two meter long. Dry matter and grain/seed yield in sweet sorghum and legumes were recorded after separating the plant parts and drying at 80 ^{o}C in an oven until a constant weight was reached. Grain moisture content was determined by dry weight basis and finally converting to 16 % for sweet sorghum and 10 % moisture content for both mung bean and soybean.

Bioethanol yield (BEY) was calculated using dry weight (t ha^{-1}) of stalk, leaves and grain of sorghum, plant stubble and seed weight of legumes, and soluble sugars, starch, cellulose and hemicellulose in dry matter as per procedures adopted by others (Institution of Japan Energy, 2006; Zhao *et al*, 2009). The following equations were used for the calculation of BEY.

BEY (soluble sugars) = DW x S_1 x F_1 x E_1 x S_2 (Eq.1)
BEY (starch) = DW x S_1 x F_2 x F_1 x E_1 x S_2 (Eq. 2)
BEY (cellulose & hemicelluloses) = DW x S_1 x F_3 x E_2 x F_1 x E_1 x S_2 (Eq. 3)

Where,
BEY = Bioethanol yield, L ha^{-1}
DW = Dry weight of plant part, t ha^{-1}
S_1 = Chemical substance in percentage of dry weight of plant part
F_1 = Conversion factor from sugar to ethanol (0.51)
E_1 = Process efficiency from sugar to ethanol (0.85)
F_2 = Conversion factor from starch to sugar (1.11)
F_3 = Conversion factor from cellulose or hemicellulose to sugar (1.11)
E_2 = Process efficiency from cellulose or hemicelluloses to sugar (0.85)
S_2 = Specific gravity of ethanol (1000/0.79)

Data analysis. Orthogonal contrast procedure was used to compare the performance of crops in sole and intercropping stand. The analysis of variance was performed for normal data and Fisher's Protected Least Significant Difference Procedure was adopted to compare the treatment effects and their interactions on growth and yield parameters of sweet sorghum, mungbean and soybean (Steel and Torrie, 1980).

RESULTS

Weather conditions. During the study period, monthly total rainfall was 41.3, 23.4, 93.1, 88.8, and 115.8 mm, average temperature was 26.3, 27.2, 28.1, 28.9, and 27.8 ^{o} C and accumulated solar radiation was 1223.0, 1297.0, 1236.3, 1614.8, and 1350.7 kwm^{-2} for January, February, March, April, and May, respectively (Figure 1).

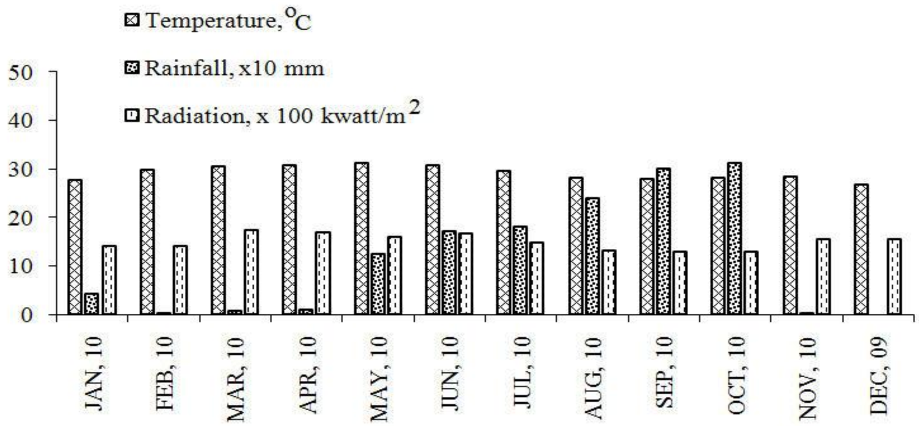

Figure 1. Accumulated values of monthly global solar radiation and rainfall, and average monthly temperature during field experiment at site in Pathumthani province, Thailand

Air quality observations. Concentrations of ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) were very high in ambient air and were significantly ($p \leq 0.001$) reduced in filtered air sampled at all growth stages (Table 1). There was a slight variation in the concentration of all gases in both ambient and filtered air.

Dry matter production. Dry matter yield (DM) in sweet sorghum was highest in sole crop of sweet sorghum (41.8 t ha^{-1}) and was significantly decreased ($p \leq 0.001$) in intercropping stand with mungbean (36.2 t ha^{-1}) (Table 2). However, sweet sorghum intercropped with soybean produced the yield at par ($p > 0.05$) compared to that of sole crop. An interaction ($p \leq 0.05$) between type of legume and N level observed for DM in intercropped sweet sorghum (Figure 2a). According to the interaction, sweet sorghum in intercropping with soybean produced higher DM (37.3-42.3 t ha^{-1}) compared to that in intercropping with mungbean (30.5-39.4 t ha^{-1}) at all levels of N. There was a significant ($p \leq 0.05$) increase in DM in response to increase in N from 30 to 60 kg ha^{-1} and further increase in N (60 to 120 kg ha^{-1}) resulted into insignificant ($p > 0.05$) response disregard to the type of legume. Resultantly, soybean and N dose of 60 or 120 kg ha^{-1} produced DM of intercropped sweet sorghum almost at par with that of sole crop of sweet sorghum.

Dry matter yield (DM) in mungbean and soybean decreased significantly ($p \leq 0.001$) in intercropping with sweet sorghum (2.4 & 1.7 t ha^{-1}, respectively) compared to sole crop stands (3.4 & 2.3 t ha^{-1}, respectively) (Table 3). Interaction between N dose and air quality treatments posed a significant ($p \leq 0.01$) variation in DM of intercropped mungbean and soybean (Fig 2b & c). The DM was highest in intercropping supplied with filtered air and N doses either of 30 or 60 kg ha^{-1} and reduced significantly due to ambient air under the same N doses. Both legumes in intercropping established with ambient air gained highest DM at

30 kg ha^{-1} N whereas that established with filtered air gained highest DM at 60 kg ha^{-1} N, and that was almost at par with that of respective sole stand.

Grain and seed yields. Grain yield of sweet sorghum in intercropping with soybean was at par ($p > 0.05$) compared to that of its sole crop (5.1 t ha^{-1}) but significantly ($p \leq 0.001$) higher compared to intercropping with mungbean (4.5 t ha^{-1}) (Table 2). Within intercropping, the yield was remained unchanged ($p > 0.05$) between the filtered and ambient air treatments but significantly ($p \leq 0.05$) affected by the interaction between intercrop legume and N dose (Fig 2d). According to the interaction, it was greater where sweet sorghum intercropped with soybean (4.8-5.5 t ha^{-1}) compared to mungbean (4.3-4.7 t ha^{-1}) at all levels of N tested. There was gradual increase in the yield in response to increasing level of N irrespective of type of legume. However, in the presence of mungbean, GY significantly differed only between the N levels of 30 and 60 kg ha^{-1} whereas in the presence of soybean, it was increased significantly with increasing N dose from 30 to 120 kg ha^{-1}. In conclusion, sweet sorghum in association with soybean established with N dose of 60 or 120 kg ha^{-1} yielded greater GY compared to that of its sole crop.

Seed yield (SY) of mungbean and soybean significantly reduced ($p \leq 0.05$) in intercropping (1.9 & 1.5 t ha^{-1}, respectively) compared to that of sole crop (2.3 & 2.3 t ha^{-1}, respectively) (Table 3). There was a significant ($p \leq 0.05$) interaction effect of N dose and air quality on SY of both legumes in intercropping with sweet sorghum (Fig 2e & f). The SY was highest due to filtered air and N dose of 30 kg ha^{-1} and yielded lower SY for mungbean and at par for soybean compared to that of respective sole crop.

Biomass production. Above ground biomass (AGB) in sweet sorghum was highest in sole cropping (46.9 t ha^{-1}) and was significantly ($p \leq 0.001$) different compared to that in intercropping with mungbean (40.7 t ha^{-1}) (Table 2). However, sweet sorghum intercropped with soybean produced AGB (45.50 t ha^{-1}) at par ($p > 0.05$) with that of its sole crop. Within intercropping significant ($p \leq 0.001$) individual influence of type of legume and N dose was observed for AGB of sweet sorghum (Table 4). The AGB was greater in intercropping with mungbean (45.5 t ha^{-1}) compared to that in intercropping with soybean (40.7 t ha^{-1}), and in intercropping established with N dose of 60 kg ha^{-1} (44.9 t ha^{-1}) or 120 kg ha^{-1} (45.9 t ha^{-1}) compared to that in intercropping established with N dose of 30 kg ha^{-1}. The AGB of mungbean and soybean decreased significantly ($p \leq 0.001$) in intercropping with sweet sorghum (4.3 & 3.2 t ha^{-1}, respectively) compared to respective sole cropping (5.7 & 4.6 t ha^{-1}, respectively) (Table 4). The biomass yield was significantly ($p \leq 0.001$) and individually affected by different levels of N and air quality. The AGB of both mungbean and soybean was significantly reduced due to N dose of 120 kg ha^{-1} (3.4 & 2.2 t ha^{-1}, respectively) compared to N dose of 60 kg ha^{-1} (4.6 & 3.7 t ha^{-1}, respectively). However, the difference in the yield was not significant ($p > 0.05$) between the N dose of 30 and 60 kg ha^{-1} in both the legumes.

Table 1. Variation in concentration of ozone, nitrogen dioxide and sulfur dioxide at different growth stages

Treatment	Weeks after seeding					
	2	4	6	8	10	12
Ozone						
Filtered air	15.05 ± 1.52	14.40 ± 3.88	12.81 ± 2.63	11.11 ± 2.09	16.74 ± 3.26	14.53 ± 2.93
Ambient air	57.44 ± 6.43	62.63 ± 2.10	55.43 ± 5.06	49.83 ± 7.76	52.65 ± 9.91	44.58 ± 3.92
LSD (p=0.05)	3.49	2.39	3.08	4.91	5.55	2.53
CV, %	14.0	9.0	13.1	23.4	23.3	12.5
Nitrogen dioxide						
Filtered air	15.14 ± 5.73	16.71 ± 4.53	12.11 ± 4.87	14.47 ± 3.48	14.25 ± 6.53	15.61 ± 9.48
Ambient air	48.37 ± 17.24	49.46 ± 13.52	47.39 ± 13.48	45.82 ± 14.28	45.17 ± 19.50	40.73 ± 12.99
LSD (p=0.05)	9.76	7.58	7.78	7.76	10.71	8.14
CV, %	44.7	33.3	38.0	37.4	52.4	42.0
Sulfur dioxide						
Filtered air	3.94 ± 0.96	4.76 ± 0.97	2.86 ± 0.93	2.39 ± 0.91	2.49 ± 0.31	2.96 ± 0.50
Ambient air	18.75 ± 6.32	17.64 ± 5.31	11.72 ± 3.80	10.49 ± 2.41	11.99 ± 6.54	14.86 ± 4.54
LSD (p=0.05)	3.33	2.74	1.95	1.26	3.47	2.42
CV, %	42.7	35.6	38.9	28.6	69.7	39.6

Table 2. Comparison of dry matter yield (DM), grain yield (GY), above ground biomass yield (AGB), and bioethanol yield (BEY) between sole crop of sweet sorghum and intercropping with mungbean and soybean using Orthogonal Contrasts.

Parameter	**Sole Crop**	**Sweet Sorghum-Mungbean**		**Sweet Sorghum-Soybean**		**MS for Error**	**CV, %**
	Variable	**MS for Contrast[1/]**	**Variable**	**MS for Contrast**	**Variable**		
DM, t ha^{-1}	41.81 ± 2.60	82.313***[2/]	36.16 ± 2.08	5.751	40.32 ± 1.73	4.270	5.4
GY, t ha^{-1}	5.06 ± 0.39	0.745***	4.53 ± 0.10	0.039	5.19 ± 0.14	0.028	3.5
AGB, t ha^{-1}	46.87 ± 2.91	98.704***	40.67 ± 4.80	4.814	45.50 ± 3.07	4.770	5.0
BEY, L ha^{-1}	17444.27 ± 901.50	22313845.800***	14805.7 ± 1567.20	743700.600	17213.60 ± 1114.70	693686.700	5.2

1/ MS contrast refers to the mean square of the contrast for specific comparison between sole crop and intercropping;
2/ ***- indicates the significance of the comparison between sole and intercropping at p=0.001.

Table 3. Comparison of dry matter yield (DM), seed yield (SY) and above ground biomass (AGB) in mungbean and soybean between sole cropping and in intercropping using Orthogonal Contrasts and mean squares.

Legume/ Parameter	Sole crop	Sweet sorghum-legume		MS for Error	CV, %
	Variable	MS for Contrast[1/]	Variable		
Mungbean					
DM, t ha^{-1}	3.42 ± 1.05	2.64***[2/]	2.41 ± 0.28	0.242	19.3
SY, t ha^{-1}	2.32 ± 0.53	0.46*	1.90 ± 0.17	0.067	13.2
AGB, t ha^{-1}	5.74 ± 0.58	5.32***	4.31 ± 1.00	0.228	10.6
Soybean					
DM, t ha^{-1}	2.33 ± 0.09	0.94***	1.72 ± 0.21	0.046	11.9
SY, t ha^{-1}	2.26 ± 0.15	1.43***	1.51 ± 0.20	0.059	15.0
AGB, t ha^{-1}	4.58 ± 0.22	4.67***	3.23 ± 0.38	0.163	11.8

1/ MS contrast refers to the mean square of the contrast for specific comparison between sole crop and intercropping;
2/ * and ***- indicate the significance of the comparison between sole and intercropping at p=0.05 and 0.001, respectively.

Table 4. Effects of intercrop legume, N dose and air quality on above ground biomass (AGB) in intercropped sweet sorghum and of N dose and air quality on AGB of mungbean and soybean compared to AGB of respective sole crops.

Treatment	Sweet sorghum	Mungbean	Soybean
Sole crop	**46.9 ± 2.9**	**5.7 ± 0.6**	**4.6 ± 0.2**
Intercropping			
Type of legume			
Mungbean	40.7 ± 4.8	-	-
Soybean	45.5 ± 3.1	-	-
LSD (p=0.05)	1.5	-	-
N dose, kg ha^{-1}			
30	38.4 ± 4.5	4.9 ± 0.7	3.8 ± 0.7
60	44.9 ± 2.5	4.6 ± 1.0	3.7 ± 1.1
120	45.9 ± 2.5	3.4 ± 0.6	2.2 ± 0.4
LSD (p=0.05)	1.8	0.6	0.5
Air quality			
Filtered air	43.8 ± 4.6	4.9 ± 0.9	3.8 ± 1.1
Ambient air	42.4 ± 4.8	3.7 ± 0.8	2.7 ± 0.6
LSD (p=0.05)	ns	0.5	0.4
CV, %	4.9	10.6	13.2

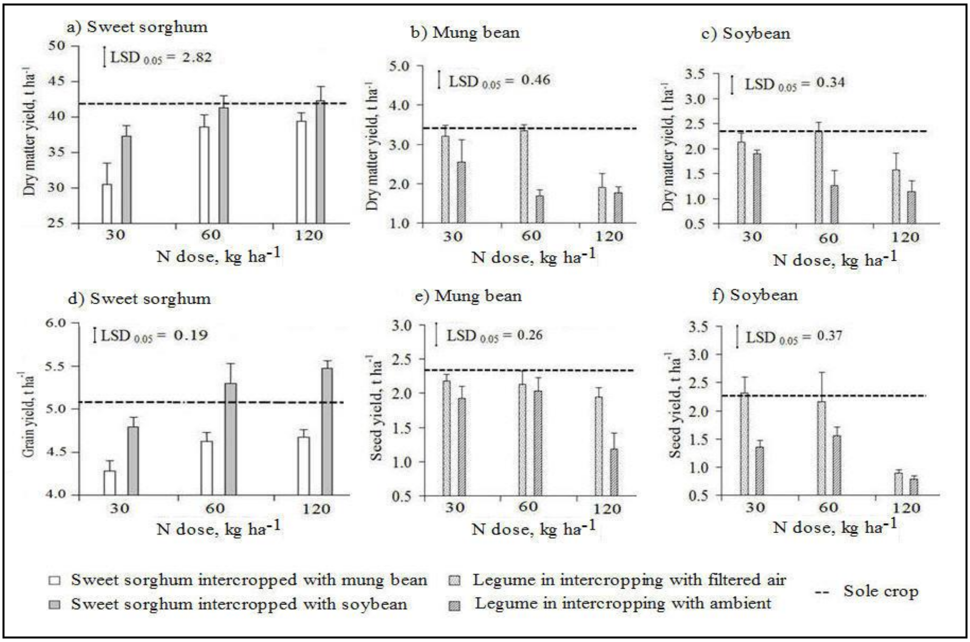

Figure 2 Two-way interactions: between type of legume and N dose for dry matter (a) and grain yield (d) of sweet sorghum and between N dose and air quality for dry matter and seed yield of mungbean (b & e) and soybean (c & f) (Performance of sole crop is shown by horizontal line).

Bioethanol Production. Bioethanol yield (BEY) in cropping system was computed using dry biomass and percent contents of chemical substances in sweet sorghum and legumes (Mungbean, Soybean) in sole and intercropping stands. The sum of the BEY of component crops (sweet sorghum & legume) in intercropping system was compared with that of sole cropping of sweet sorghum (Table 5). Bioethanol yield considering total biomass of sweet sorghum was highest in its sole cropping (17751.4 L ha^{-1}) and was significantly different compared to that of total biomass of sweet sorghum-mungbean intercropping (14805.7 L ha^{-1}) but at par with that of sweet sorghum-soybean intercropping (17213.6 L ha^{-1}) indicating no advantage in intercropping for bioethanol production. However, by considering the grain (sweet sorghum) and seed (legumes) portion as a food sources for high values of carbohydrate, protein, fat and digestible energy, the remaining dry matter can be considered for bioethanol production. Dry matter yield of bioethanol had significant ($p \leq 0.001$) individual affect of type of legume, N dose and air quality and was higher in sweet sorghum-soybean intercropping (15482.2 L ha^{-1}) compared to sweet sorghum-mungbean intercropping (13125.5 L ha^{-1}), in N dose of 60 kg ha^{-1} (14971.9 L ha^{-1}) compared to N dose of 30 kg ha^{-1} (12925.7 L ha^{-1}) and in filtered air (14671.7 L ha^{-1}) compared to ambient air (13936.1 L ha^{-1}) (Table 4). There was no significant interaction effect between or among the treatments for BEY in intercropping system.

Table 5. Effect of legume type, N dose and air quality on bioethanol yield (BEY) of intercropping dry matter, intercroppingsweet sorghum and intercropping biomass compared to that of sweet sorghum sole crop.

Treatment	Intercropping Dry matter	Sweet sorghum biomass + legume dry matter	Intercropping biomass
Sole cropped sweet sorghum	17623.9 ± 1342.5	17751.4 ± 1144.4	17751.4 ± 1144.4
Intercropping			
Type of legume			
Mungbean	13125.5 ± 1518.5	13395.8 ± 1616.5	14805.7 ± 1567.2
Soybean	15482.2 ± 1024.3	16171.1 ± 1114.8	17213.6 ± 1114.7
LSD (p=0.05)	536.4	490.0	573.0
N dose, kg ha^{-1}			
30	12925.7 ± 1881.1	13146.9 ± 2011.8	14568.6 ± 1899.9
60	14971.9 ± 1284.0	15442.2 ± 1380.6	16739.8 ± 1333.8
120	15013.9 ± 1197.1	15761.2 ± 1367.2	16720.5 ± 1293.4
LSD (p=0.05)	657.0	600.1	701.8
Air quality			
Filtered air	14671.7 ± 1722.8	15013.0 ± 1962.8	16422.1 ± 1774.1
Ambient air	13936.1 ± 1743.8	14553.9 ± 1992.4	15597.2 ± 1805.7
LSD (p=0.05)	536.4	490.0	573.0
CV, %	5.5	4.8	5.2

DISCUSSION

Sweet sorghum is grown for multiple purposes globally, i.e. a source of food, feed, and fiber (Dajue, 1995). It can tolerate adverse conditions with respect to water (Vasilakoglou, 2011), nutrients (Han *et al*., 2011), and other stresses. Due to these inherent abilities, sweet sorghum is preferred to many other crops in stress-prone ecosystems (Lithourgidis, 2011). Due to its slow initial growth, the potential for enhancing the yields in lands devoted to sweet sorghum could be expected only with the practice of intercropping with legumes, and the current study evaluated the potential of increasing crop yield, while targeting the production of bioethanol using crop residue as biomass. Two legumes (viz. soybean and mungbean), three N rates and air quality effects were evaluated.

Sweet sorghum has a slow initial growth until around 40 days after emergence, and by when plant has approximately 12 leaves, 40 cm in height and 2.5 of LAI. There is ample ground area with solar radiation left during this period (Best, 1994). Following the jointing stage, the plant attains a rapid growth phase and reaching a plant height of around 300 cm and LAI of about 5 in the next 26 days with per day increment of 10 cm in height (Best, 1994). Therefore, short season legume has ample opportunities to emerge, grow and reach near flowering stage by the time sweet sorghum starts its rapid growth. In the next 20 days, pods and seeds could be produced with minimal impact from sweet sorghum. This qualifies the intercropping sweet sorghum with legumes like mungbean or soybean together. However the level of interference of the two components would determine the benefits of the intercropping patterns.

Average values of dry matter, grain and AGB of intercropped sweet sorghum significantly reduced by 13.5, 10.5 and 13.2 %, respectively, when associated with mungbean compared to the same parameters in the sole crop. The reduction with soybean was 3.5, 0, and 2.9, respectively. This shows that soybean exerted less pressure on associated sweet sorghum compared to mungbean. The increased pressure by mungbean could primarily attributed to higher plant density (222,222 plants ha^{-1}) and its rapid and profuse growth (Dhope *et al*, 1992), compared to soybean (population of 148148 plants ha^{-1}). The lower intra-row spacing and determinate growth may have enhanced the aggressivity of mungbean compared to soybean. There was a non competitive and accommodative environment for sweet sorghum when associated with soybean with greater ability to fix atmospheric nitrogen (56–89% of plant N) compared to mungbean (45–76% of plant N) which could be made available for the neighboring crop as concluded (Tien *et al*, 2002). The DM, grain yield and AGB of sweet sorghum decreased significantly by 10.3, 12.7 and 10.6 %, respectively, when associated with mungbean compared to soybean. The results are also in agreement with the observations of Subbian and Selvaraju (2000) and Singh and Jadhav (2003) where greater yield reduction of sorghum occurred when intercropped with green gram or pigeon pea compared to soybean. The DM, grain yield and AGB in intercropped sweet sorghum decreased significantly by 15.2, 8.5 and 14.4 %, respectively, with 30 kg ha^{-1} N compared to 60 kg ha^{-1}. Sweet sorghum being a cereal prefers external N from soil, and hence reduction in the supply of N from fertilizer usually brings reductions in growth and yield.

This is in agreement with the findings of Waghmaref and Singh (1984), where increasing N levels from 40 to 80 and 80 to 120 kg ha^{-1} increased grain yield in sorghum by 8.6, 16.1 and 18.2 % in intercropping system, but is in disagreement with Latha and Durai (2003) who observed the highest grain yield in intercropped sorghum at 80 kg ha^{-1} N compared to 40 or 60 kg ha^{-1}. Interaction between intercrop soybean and N dose (60 kg ha^{-1}) produced DM, GY and AGB of intercropped sweet sorghum at par with that of interaction between type of legume and N dose and also with sole cropping of sweet sorghum.

The purpose of growing legumes with sweet sorghum was to gain additional yields from legumes by utilizing unused and available resources as early as possible before sweet sorghum commences its high demanding period for resources. Addition of yield by intercropped legume to the production of the main crop would give yield advantages (Willey, 1979). Average DM, seed yield and AGB of mungbean were reduced by 29.5, 18 and 25.0 % respectively, when intercropped with sweet sorghum compared to sole cropping due to competition, and the reductions were 26, 33 and 29.4 %, respectively, of soybean compared to sole cropping. This reduction in could partly be attributed to competition for solar radiation as shading occurs from sweet sorghum due to higher plant height than legumes and shading and some alellopathic effects of sweet sorghum (Moosavi *et al*, 2011).

Individual as well as interaction between N dose and air quality on DM and seed yield of intercropped mungbean or soybean were significant. Nitrogen dose of 20 kg ha^{-1} and filtered air produced DM and GY almost at par with respective sole crops. Yield parameters in intercropped legumes gradually reduced as the level of N increased. The possible reasons could be that a) increasing N level increases the growth of sweet sorghum leading to increase shading thus reducing photosynthesis of legume (Best, 1994), and b) increasing N level decreases the N fixation ability in root nodules (Salisbury and Ross, 1978), thus making the legume to compete with stronger cereal for soil N. Therefore, legume was suppressed more in the current study. At lower N doses, sweet sorghum showed a reduced growth and had little shading effect on adjacent legume, and also N fixing ability may not have much interrupted. Both these effects appeared to have given the advantage to legume. Reduction in growth and yield parameters of intercrop cowpea due to increased growth of associated cereal was also observed by Willey (1979) and Ofori and Stern (1986).

Under ambient air, DM, grain yield and AGB of intercropped mungbean were significantly reduced (by 29.0, 20.5 & 24.2 %, respectively) and of intercropped soybean (by 29.0, 16.0 & 30.0 %, respectively) compared to that when grown under filtered air. Such reductions could be due to variability in quality of air and synergistic influence of air pollutants, i.e. O_3, NO_2, and SO_2 etc. In ambient air of the experimental site, the concentrations of ozone were 57.4, 62.6, 55.4, 49.8, 52.7, and 44.9 ppb, nitrogen dioxides 48.4, 49.5, 47.4, 45.8, 45.2, and 40.7 ppb and sulfur dioxide 18.8, 17.6, 11.7, 10.5, 12.0, and 14.9 ppb at 2, 4, 6, 8, 10, and 12 weeks after seeding, respectively.

Ozone level above 40 ppb is known to impair the cellular activities including the photosynthetic capacity of dicot species (Karenlampi and Skarby, 1996) and increased leaf senescence (Ashmore and Marshall, 1999). Similarly, NO_2 level above 53 ppb has been reported to have physiological effects on plants (EPA, 2012) and SO_2 level above 250 ppb causes visible and invisible injuries by reacting with cuticular waxes and its dissociation to sulphite or bisulphate (EPA, 2012). According to the observations, concentrations of all three pollutants were well below their threshold levels for monocots, and this may be the reason for sweet sorghum not been affected. However, the concentration of O_3 out of the three studied pollutants was above the threshold level of the sensitivity for dicot species, and legume being a dicot, this might be the reason for the reduction of growth and yield parameters shown in mungbean and soybean under ambient air containing pollutants compared to filtered air. Apart from the individual effects of air pollutants, Ashenden and Mansfield (1978) and Clag (1996) reported the possibility of synergistic effects, so that such effects may have negatively caused growth and yields of mungbean and soybean.

Reductions in growth and yield parameters of mungbean due to combined influence of air pollutants (O_3, NO_2, SO_2) were also observed by Agrawal *et al* (2006), where daily mean O_3, NO_2, SO_2 concentrations varied from 9.7 to 58.5, 11.7 to 80.1, 8.05 to 32.2 ppb, respectively. Similar reductions in seed yield of bean plants due to air pollution were also noted by Agrawal *et al* (2003) and Tonneijck and Van Dijk (1998).

Bioethanol yield in sweet sorghum-mungbean association was reduced by 15 % and at par in sweet sorghum-soybean association compared to the sole crop of sweet sorghum. This was attributed to the negative influence of competition on AGB in intercropping compared to sole crop of sweet sorghum. The BEY was reduced more in sweet sorghum-mungbean association (15%) than sweet sorghum-soybean association. Similarly, greater decline in BEY occurred at N dose of 30 kg ha^{-1} (by 12.3 %) compared to 60 or 120 kg ha^{-1}, and this reduction was attributed to the reduction in dry matter and grain yield of sweet sorghum. The reduction in BEY of intercropping due to air pollution was 4.7 % compared to filtered air. The higher BEY in filtered air could be due to the increased plant productivity of legumes compared to ambient air. With the filtering out of the pollutants, legumes were able to acquire a better growth and competitiveness compared to the environment with ambient air. However, this increase in the dry matter and yield of intercropped legume under filtered air was not adequate to compensate the loss of yield occurred in sweet sorghum due to increased completion from the legumes under the filtered air.

Over all, growth and yield parameters of sweet sorghum were improved by the treatments, whereas the same parameters declined in legumes. Simultaneous seeding of both crops produced a greater competitiveness and led to sharing available above and below ground resources. Enhanced growth of sweet sorghum due to increased N caused shading over legume intercropped between its rows, whereas better growth of legumes under filtered air created a competitive situation for sweet sorghum, thus decreasing the productivity of the system in terms of BEY. However, it brings benefits when grains of sweet sorghum and seeds of legumes are used for food purpose as in the previous study of Arshad and Ranamukhaarachchi (2012) and the plant dry matter is used for BEY purpose, as in the current study.

CONCLUSIONS

The research work showed the dual production potential of intercropping sweet sorghum and legume for both food and bioethanol. The grains of sweet sorghum and seed of legumes can be used for food needs and the dry matter of the system may be processed for bioethanol production. The both out puts provide added benefits of intercropping sweet sorghum with legumes. Therefore, intercropping sweet sorghum with mungbean and soybean in simultaneous seeding provided with 60 kg ha^{-1} of N under filtering of air pollutants enhanced the performance of legumes, grain yields and bioethanol production

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EFEKAT TIPA MAHUNARKE, DOZE AZOTA I KVALITETA VAZDUHA NA PROIZVODNJ BIOAMASE I BIOETANOLA KOD MEĐUUSJEVA SLATKOG SIRKA-LEGUMA

SAŽETAK

Slatki sirak se uzgaja kao pojedinačan i potencijalni energetski usjev u područjima sa ograničenom vodom. Posjeduje inherentni potencijal sadnje kao međuusjev sa mahunarkama za proizvodnju kako hrane, tako i bioetanola. Kako bi se istražio ovaj potencijal, proučavali smo nekoliko šema međuusjeva sa dvije mahunarke (tj. zlatni grah i soje), tri doze azota (tj. 30, 60 i 120 kg ha^{-1}) i dva uslova kvaliteta vazduha (tj. filtriran vazduh i abijentalni vazduh) kod tri pojedinačna usjeva (slatki sirak, zlatni grah i soje) u potpuno nasumičnom dizajnu sa po tri ponavljanja u sušnoj sezoni. Vršeno je poređenje suve tvari (DM), zrna, nadzemne mase (AGB) i obračunatog prinosa bioetanola (BEY) slatkog sirka i mahunarki u pojedinačnim i međuusjevnim lejama i u međuusjevu. Suva tvar, prinos zrna i AGB slatkog sirka se značajno smanjio ($p \leq 0.001$) u međuusjevu sa zlatnim grahom (36.2, 4.5 i 40.7 t ha^{-1}, odnosno) ali je ostao na istom nivou ($p > 0.05$) kod međuusjeva sa sojom (40.3, 5.2 & 45.5 t ha^{-1}, odnosno) ukoliko se uporedi sa pojedinačnim usjevom slatkog sirka (41.8, 5.1 & 46.9 t ha^{-1}, odnosno). Tretman azotom u količini 60 kg ha^{-1} je proizveo optimiziranu suvu tvar, zrno/sjeme, AGB i BEY u poređenju sa ostalom količinom azota. Uticaj ambijentalnog vazduha (zagađenog) na usjev slatkog sirka nije bio na značajnom nivou ($p>0.05$); međutim, filtrirani vazduh je značajno poboljšao ($p \leq 0.05$) sadržaj suve tvari i prinos sjemena kod međuusjeva sa mahunarkama. Zasad slatkog sirka sa zlatnim grahom ili sojom kod istovremenog sijanja uz 60 kg ha^{-1} azota pod filtriranim zagađivačima vazduha je unapredila karakteristioke mahunarki, prinos usjeva i proizvodnju bioetanola.

Ključne riječi: Zagađivači vazduha, bioetanol, suva materija, međuusjev, azot, mahunarke, slatki sirak