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Full Length Research Paper

Heterosis and leaf curl virus resistance in rainy season tomato under North Indian conditions

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Purpose of this study was to identify heterotic hybrids of tomato resistant to leaf curl virus disease. Eleven parental lines and their 55 one-way F_1 crosses produced in a diallel mating design were evaluated for fruit yield, fruit quality, tomato leaf curl virus (TLCV) resistance and other important traits at Research Farm of the Department of Vegetable Science, Punjab Agricultural University, Ludhiana (India) during autumn of 2012. Parent 2-1 showed no TLCV symptoms throughout the growth period under natural epiphytotic conditions. The remaining lines showed mild to very severe disease infection. Seventeen of the crosses were completely free from TLCV symptoms under natural field conditions. Heterosis was worked out over mid-parent, better parent and commercial resistant check NS 524. The hybrids outperforming the best check (NS 524) included 102-13-6-1 × 2-1 for marketable (66.15%) and total fruit yield (63.12%), Punjab Chhuhara × 58-18-1-1 for dry matter content (43.89%), 58-11-1-1 × 102-13-6-1 for fruit weight (34.14%), 102-1-6-1 × 115-1-8-1 for number of locules (-45.15%), 56-14-7-1 × 58-18-1-1 for lycopene content (61.06%), 102-1-6-1 × 58-18-1-1 for TSS content (19.32%), 58-18-1-1 × 55-26-1-1 for pericarp thickness (49.56%), 102-1-6-1 × 115-1-8-1 for polar diameter (32.07%) and 115-1-8-1 × 55-26-1-1 for equatorial diameter (19.07%). Based on the overall performance, four crosses *viz*., 102-8-5-1 × 7-5-1, 102-13-6-1 × 55-26-1-1, 58-11-1-1 × 58-18-1-1 and 102-13-6-1 × 2-1 were identified as promising. These hybrids recorded fruit yield of 2.22, 2.29, 2.70 and 3.24 kg plant^{-1}, respectively, which was either at par with or significantly better than the resistant check NS 524 (1.95 kg plant^{-1}). The hybrids also had acceptable fruit shape index (0.97-1.20) and fruit size (36.66-96.66 g).

Key words: Tomato, heterosis, Diallel, tomato leaf curl virus (TLCV).

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a major vegetable crop grown throughout the world including tropical, subtropical and temperate regions. On global basis, it is planted on 4.4 million hectares with a total production of 161.79 million tonnes (Anonymous, 2012). India is the third largest tomato producer in the world after China and USA, accounting for about 8% of the world tomato production. It is cultivated over an area of about 0.905

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million hectares with the total production of 19.10 million tonnes and productivity of 21.10 t ha^{-1} (Anonymous, 2013).

Leaf curl virus is a serious disease of tomato and its incidence can reach up to 100% with yield losses often exceeding 90% (Saikia and Muniyappa, 1989). Tomato cultivation, especially in autumn season in North India and in summer season in South India is adversely affected due to high incidence of TLCV. The disease is caused by different species of genus *Begomovirus* (Family Geminiviridae), which are transmitted by whitefly (*Bemisia tabaci* Genn.). Managing the disease with pesticides has been a difficult task because of the rapid development of pest resistance to most insecticides (Horowitz et al., 2005). In recent years, the hybrid cultivars of tomato have become very popular with the growers due to their superior *per se* performance, which is manifested due to better plant vigour, faster growth and development, earliness, increased productivity and higher levels of resistance to biotic and abiotic stresses (Yordanov, 1983). Punjab Agricultural University has recommended three hybrids of tomato *viz*., TH 2312, TH 802 and TH 1 for cultivation in the state. However, all the three hybrids are susceptible to TLCV and are, therefore, not suitable for cultivation in the rainy season. Recently, the university has developed some breeding lines possessing high degree of resistance to TLCV. These lines will serve as the potential source for the development of TLCV resistant hybrids suitable for cultivation in rainy season.

Choice of parents for hybridization is one of the critical and most important tasks for plant breeders. The common approach for selecting the parents based on *per se* performance does not necessarily lead to desired results. Therefore, the present investigation was undertaken to identify tomato hybrids resistant to TLCV and suitable for cultivation in rainy season.

MATERIALS AND METHODS

The present investigation was carried out at the Department of Vegetable Science, Punjab Agricultural University Ludhiana, India during 2011-12 and 2012-13. The material for the present study comprised of eleven parents *viz*., Punjab Chhuhara, 58-11-1-1 , 56-14-7-1, 102-13-6-1, 102-1-6-1, 102-8-5-1, 115-1-8-1, 58-18-1-1, 55-26-1-1, 7-5-1, 2-1 along with one resistant check hybrid NS-524. Fifty-five F_1 crosses (excluding reciprocals) involving 11 parents were made in a diallel fashion during February-March 2012. The parents, except Punjab Chhuhara, were selectively chosen for their resistance to TLCV. The experimental material comprising 55 F_1 hybrids, 11 parental lines and check NS-524 were sown and raised in plastic trays in July and transplanted in August in an Augmented Randomized Block Design. All the cultural practices were followed as per the recommendations in Package of Practices for Vegetable Crops (Anonymous, 2013a). To increase inoculum pressure, one row of TLCV susceptible cv. Punjab Chhuhara was planted after every fifth row of the experimental plots. Plants were examined at weekly intervals for TLCV symptoms. Disease spread and the severity of symptoms were recorded according to the disease severity scale described by Muniyappa et al. (1991). Data for various horticultural traits were recorded from five randomly selected plants excluding border plants. Observations were recorded on 10 economic traits *viz.*, marketable yield (kg plant^{-1}), total fruit yield (kg plant^{-1}), equatorial diameter (cm), polar diameter (cm), dry matter (%), total soluble solids (%), lycopene (mg 100^{-1} g of fresh weight), number of locules per fruit, pericarp thickness (cm) and average fruit weight (g). Mean performance of parents for different characters is presented in Table 1.

RESULTS AND DISCUSSION

There were significant differences in the performance of parents, hybrids and checks for fruit yield, horticultural traits and TLCV resistance. The genetic differences exhibited by the hybrid progenies could be exploited through heterosis breeding with the identification of superior performing F_1 hybrids.

Estimation of heterosis

The available literature on heterosis in tomato provided evidence that this phenomenon is not limited to cross-pollinated crops. One of the theories of this performance was that natural cross-pollination predominated within the wild forms of tomato in the centers of their origin. Therefore, crosses between tomato lines might be considered as F_1 between inbred lines of a species, which is naturally cross-pollinating. The exploitation of heterosis phenomenon can prove a potential tool in the hands of plant breeders for the improvement of this crop.

The results pertaining to mean performance and percent heterosis over better parent, mid parent and NS-524 are reported in Table 2.

Marketable yield (kg plant^{-1})

Four cross combinations *viz*., 102-8-5-1 × 7-5-1, 102-13-6-1 × 55-26-1-1, 58-11-1-1×58-18-1-1 and 102-13-6-1 × 2-1, exhibited positive heterosis over NS-524. These crosses outperformed the resistant check NS 524 by 13.85, 17.44, 38.46 and 66.15%, respectively. Cheema et al. (1996) also reported significant positive heterosis for marketable yield.

Total fruit yield (kg plant^{-1})

Four cross combinations, namely 102-13-6-1 × 55-26-1-1, 102-8-5-1 × 7-5-1, 58-11-1-1 × 58-18-1-1 and 102-13-6-1 × 2-1, were identified as promising for total fruit yield. These crosses outperformed the resistant check NS-524 by 14.81, 30.12, 39.20 and 63.12%, respectively. Heterosis for fruit yield was also reported by Dod and Kale (1992), Kumar et al. (1995), Chaudhary and Malhotra (2001), Tiwari and Lal (2004), Mahendrakar et al. (2005) and Premalakshme et al. (2005) and Gaikwad et al. (2009).

Table 1. Mean performance of parental liness for different characters.

Parents	Marketable yield (kg plant^{-1})	Total fruit yield (kg plant^{-1})	Diameter (cm) Equatorial	Diameter (cm) Polar	Dry matter (%)	TSS (^{o}Brix)	Lycopene (mg 100 g^{-1})	Number of locules	Percarp thickness (cm)	Fruit weight (g)
Punjab Chhuhara	0.44	0.50	4.41	5.84	4.73	4.85	3.2	3.13	0.53	30.12
58-11-1-1	1.07	1.12	4.40	4.77	5.37	4.04	2.53	4.07	0.25	65.26
56-14-7-1	1.02	1.17	4.81	4.49	3.77	4.15	3.78	2.12	0.59	29.86
102-13-6-1	0.85	1.33	5.53	4.68	3.97	3.64	1.82	3.84	0.53	70.48
102-1-6-1	0.09	0.37	6.20	5.11	3.95	4.26	2.09	4.28	0.58	117.14
102-8-5-1	1.48	1.61	5.09	4.04	3.90	4.09	3.73	2.10	0.49	61.88
115-1-8-1	0.88	1.34	5.13	4.43	4.09	4.34	4.67	3.00	0.35	47.33
58-18-1-1	1.30	1.41	4.94	3.67	4.26	4.09	2.00	3.63	0.77	65.79
55-26-1-1	0.59	0.73	4.61	4.22	4.73	4.30	2.89	3.21	0.53	76.87
7-5-1	1.05	1.38	4.73	5.16	4.28	4.06	1.63	3.52	0.44	67.87
2-1	1.67	1.89	4.49	5.57	3.84	4.89	3.96	2.88	0.52	59.41
NS524 (Check)	1.96	2.09	5.52	5.16	4.18	4.57	3.10	3.63	0.59	91.40

Table 2. Mean performance of F_1 hybrids and percentage increase / decrease (heterosis) over better parent (BP), mid parent (MP) and resistant check NS 524.

Hybrids	Marketable yield (kg plant^{-1})				Total fruit yield (kg plant^{-1})				Equalarial diameter (cm)				Polar diameter (cm)				Dry matter (%)			
		Percentage increase/decrease over				Percentage increase/decrease over				Percentage increase/decrease over				Percentage increase/decrease over				Percentage increase/decrease over		
	Mean	Better parent	Mid parent	NS-524	Mean	Better parent	Mid parent	NS-524	Mean	Better parent	Mid parent	NS- 524	Mean	Better parent	Mid parent	NS-524	Mean	Better parent	Mid parent	NS- 524
PC×58-11-1-1	1.28	19.63**	69.54**	-34.36	1.43	27.68**	76.54**	-31.59	5.05	14.51**	14.64**	-8.48	5.29	-9.42**	-0.28	2.59	4.24	-21.04**	-16.04**	1.51
PC×56-14-7-1	0.76	-25.49**	4.11	-61.03	0.86	-26.50**	2.99	-58.86	4.96	3.12	7.59**	-10.11	5.49	-5.99*	6.29**	6.47**	4.45	-5.92**	4.71**	6.54**
PC×102-13-6-1	0.78	-8.24	20.93	-60.00	1.03	-22.56**	12.57	-50.73	4.51	-18.44**	-9.26**	-18.26	5.44	-6.85**	3.42	5.50**	4.4	-6.98**	1.15	5.34**
PC×102-1-6-1	1.20	172.73**	352.83**	-38.46	1.46	192.00**	235.63**	-30.16	4.46	-28.06**	-15.93**	-19.17	4.74	-18.84**	-13.42**	-8.07	3.81	-19.45**	-12.21**	-8.78
PC×102-8-5-1	1.42	-4.05	47.92**	-27.18	1.54	-4.35	45.97**	-26.33	5.11	0.39	7.58**	-7.39	4.1	-29.79**	-17.00**	-20.49	4.01	-15.22**	-7.07**	-3.99
PC×115-1-8-1	1.08	22.73**	63.64**	-44.62	1.18	-11.94	28.26**	-43.55	4.61	-10.14**	-3.35	-16.45	5.04	-13.70**	-1.85	-2.26	4.37	-7.61**	-0.91	4.63**
PC×58-18-1-1	1.01	-22.31**	16.09	-48.21	1.16	-17.73**	21.47**	-44.51	5.26	6.48**	12.51**	-4.67	5.69	-2.57	19.66**	10.35**	6.01	27.06**	33.70**	43.89**
PC×55-26-1-1	0.74	25.42**	43.69**	-62.05	1.21	65.75**	96.75**	-42.12	4.22	-8.46**	-6.43**	-23.52	5.26	-9.93**	4.57*	2.01	4.15	-12.26**	-12.26**	-0.64
PC×7-5-1	1.97	87.62**	164.43**	1.03	2.11	52.90**	124.47**	0.93	5.27	11.42**	15.32**	-4.49	5.05	-13.53**	-8.18**	-2.06	4.21	-10.99**	-6.55**	0.79
PC×2-1	0.49	-70.66**	-53.55**	-74.87	0.79	-58.20**	-33.89**	-62.21	6.02	34.08**	35.28**	9.10**	4.4	-24.66**	-22.87**	-14.67	3.99	-15.64**	-6.88**	-4.47
58-11-1-1 ×56-14-7-1	1.26	17.76*	20.57	-35.38	1.37	17.09**	19.65*	-34.46	5.21	8.32**	13.14**	-5.58	6.57	37.74**	41.90**	27.42**	4.89	-8.94**	7.00**	17.07**
58-11-1-1×102-13-6-1	1.14	6.54	18.75	-41.54	1.46	9.77	19.18*	-30.16	4.47	-19.17**	-9.97**	-18.99	5.2	9.01**	10.05**	0.85	4.6	-14.34**	-1.50	10.13**
58-11-1-1×102-1-6-1	1.75	63.55**	201.72**	-10.26	1.94	73.21**	160.40**	-7.20	4.54	-26.77**	-14.34**	-17.72	4.57	-10.57**	-7.49**	-11.37	4.54	-15.46**	-2.58	8.70**
58-11-1-1×102-8-5-1	1.81	22.30**	41.96**	-7.18	1.93	19.88**	41.39**	-7.68	5.87	15.32**	23.71**	6.38**	5.3	11.11**	20.32**	2.79	4.27	-20.48**	-7.87**	2.23
58-11-1-1×115-1-8-1	2.06	92.52**	111.28**	5.64	2.16	61.19**	75.61**	3.33	5.2	1.36	9.13**	-5.76	5.18	8.60**	12.61**	0.46	5.77	7.45**	21.99**	38.14**
58-11-1-1×58-18-1-1	2.7	107.69**	127.85**	38.46**	2.91	106.38**	130.04**	39.20**	6.14	24.29**	31.48**	11.28**	5.07	6.29**	20.14**	-1.67	5.11	-4.84**	6.13**	22.34**
58-11-1-1×55-26-1-1	1.88	75.70**	126.51**	-3.59	2.02	80.36**	118.38**	-3.37	3.94	-14.53**	-12.54**	-28.59	3.97	-16.77**	-11.68**	-23.01	4.92	-8.38**	-2.57	17.79**

Table 2. Contd.

58-11-1-1×7-5-1	1.47	37.38**	38.68**	-24.62	1.77	28.26**	41.60**	-15.33	4.84	2.33	6.02**	-12.28	5.12	-0.78	3.12	-0.71	4.58	-14.71**	-5.08**	9.65**
58-11-1-1x2-1	1.27	-23.95**	-7.30	-34.87	1.67	-11.64	10.96	-20.11	4.27	-4.90*	-3.94*	-22.61	4.43	-20.47**	-14.31**	-14.09	4.54	-15.46**	-1.41	8.70**
56-14-7-1×102-13-6-1	1.23	20.59**	31.55**	-36.92	1.4	5.26	12.00	-33.03	4.87	-11.93**	-5.80**	-11.74	4.64	-0.85	1.20	-10.01	4.29	8.06**	10.85**	2.71
56-14-7-1×102-1-6-1	1.09	6.86	96.40**	-44.10	1.23	5.13	59.74**	-41.16	4.81	-22.42**	-12.62**	-12.83	4.56	-10.76**	-5.00*	-11.57	5.22	32.15**	35.23**	24.98**
56-14-7-1×102-8-5-1	1.25	-15.54**	0.00	-35.90	1.34	-16.77*	-3.60	-35.90	4.46	-12.38**	-9.90**	-19.17	4.99	11.14**	17.00**	-3.23	4.59	17.69**	19.69**	9.89**
56-14-7-1×115-1-8-1	0.78	-23.53**	-17.89	-60.00	0.83	-38.06**	-33.86**	-60.30	5.53	7.80**	11.27**	0.22	4.58	2.00	2.69	-11.18	3.98	-2.69	1.27	-4.71
56-14-7-1×58-18-1-1	1.18	-9.23	1.72	-39.49	1.35	-4.26	4.65	-35.42	4.78	-3.24	-1.95	-13.37	4.73	5.35*	15.93**	-8.27	4.16	-2.35	3.61*	-0.40
56-14-7-1×55-26-1-1	1.01	-0.98	25.47*	-48.21	1.28	9.40	34.74**	-38.77	5.13	6.65**	8.92**	-7.03	5.08	13.14**	16.65**	-1.48	3.95	-16.49**	-7.06**	-5.43
56-14-7-1×7-5-1	1.75	71.57**	117.39**	-10.26	1.99	70.09**	109.47**	-4.81	5.47	13.72**	16.14**	-0.86	4.93	9.80**	13.20**	-4.39	3.68	-22.20**	-13.41**	-11.89
56-14-7-1×2-1	1.37	-17.96*	1.86	-29.74	1.43	-24.34**	-6.54	-31.59	4.66	-3.12	0.22	-15.54	4.78	-14.18**	-4.97	-7.30	4.38	14.06**	15.11**	4.86**
102-13-6-1×102-1-6-1	1.38	62.35**	193.62**	-29.23	1.51	13.53*	77.65**	-27.77	5.39	-13.06**	-8.10**	-2.31	5.64	10.37**	15.22**	9.38**	4.05	2.02	2.27	-3.04
102-13-6-1×102-8-5-1	1.53	3.38	31.33**	-21.54	1.79	11.18	21.77**	-14.37	5.79	4.70*	9.04**	4.93**	5.11	9.19**	17.20**	-0.90	4.18	5.29**	6.23**	0.08
102-13-6-1×115-1-8-1	0.51	-42.05**	-41.04**	-73.85	0.84	-37.31**	-37.08**	-59.82	6.13	10.85**	15.01**	11.10**	4.64	-0.85	1.87	-10.01	3.98	-2.69	-1.24	-4.71
102-13-6-1×58-18-1-1	0.78	-40.00**	-27.44*	-60.00	1.11	-21.28**	-18.98**	-46.90	5.26	-4.88*	0.48	-4.67	4.47	-4.49	7.07**	-13.31	4.05	-4.93**	-1.58	-3.04
102-13-6-1×55-26-1-1	2.29	169.41**	218.06**	17.44**	2.4	80.45**	133.01**	14.81**	5.84	5.61**	15.19**	5.84**	5.4	15.38**	21.35**	4.72**	4.34	-8.25**	-0.23	3.91*
102-13-6-1×7-5-1	1.49	41.90**	56.84**	-23.59	1.63	18.12**	20.30*	-22.03	5.74	3.80	11.89**	4.03**	5.2	0.78	5.69*	0.85	4.48	4.67*	8.61**	7.26**
102-13-6-1×2-1	3.24	94.01**	157.14**	66.15**	3.41	80.42**	111.80**	63.12**	5.22	-5.61**	4.19*	-5.40	5.37	-3.59	4.78*	4.14*	4.39	10.58**	12.42**	5.10**
102-1-6-1×102-8-5-1	1.76	18.92*	124.20**	-9.74	2.13	32.30**	115.15**	1.89	4.66	-24.84**	-17.45**	-15.54	4.49	-12.13**	-1.86	-12.92	3.78	-4.30*	-3.69	-9.50
102-1-6-1×115-1-8-1	1.34	52.27**	176.29**	-31.28	1.47	9.70	71.93**	-29.68	4.73	-23.71**	-16.50**	-14.28	6.81	33.27**	42.77**	32.07**	4.3	5.13**	6.97**	2.95
102-1-6-1×58-18-1-1	1.02	-21.54**	46.76**	-47.69	1.1	-21.99**	23.60**	-47.38	5.3	-14.52**	-4.85*	-3.95	5.55	8.61**	26.42**	7.63**	4.08	-4.23*	-0.61	-2.32
102-1-6-1×55-26-1-1	1.23	108.47**	261.76**	-36.92	1.36	86.30**	147.27**	-34.94	5.7	-8.06**	5.46**	3.30*	4.6	-9.98**	-1.39	-10.79	4.93	4.23*	13.59**	18.03**
102-1-6-1×7-5-1	1.22	16.19	114.04**	-37.44	1.3	-5.80	48.57**	-37.81	4.86	-21.61**	-11.07**	-11.92	5.31	2.91	3.41	2.98	4.04	-5.61**	-1.82	-3.28
102-1-6-1×2-1	0.6	-64.07**	-31.82	-69.23	0.73	-61.38**	-35.40**	-65.08	5.16	-16.77**	-3.46	-6.48	5.48	-1.62	2.62	6.28**	4.47	13.16**	14.76**	7.02
102-8-5-1×115-1-8-1	1.63	10.14	38.14**	-16.41	1.69	4.97	14.58	-19.16	4.45	-13.26**	-12.92**	-19.35	4.12	-7.00**	-2.72	-20.10	4.15	1.47	3.88	-0.64
102-8-5-1×58-18-1-1	0.78	-47.30**	-43.88**	-60.00	1.1	-31.68**	-27.15**	-47.38	4.8	-5.70*	-4.29*	-13.01	4.81	19.06**	24.77**	-6.72	4.43	3.99*	8.58**	6.06
102-8-5-1×55-26-1-1	0.92	-37.84**	-11.11	-52.82	1.25	-22.36**	6.84	-40.20	5.6	10.02**	15.46**	1.49	5.21	23.46**	26.15**	1.04	4.06	-14.16**	-5.91**	-2.80
102-8-5-1×7-5-1	2.22	50.00**	75.49**	13.85**	2.72	68.94**	81.94**	30.12**	6.11	20.04**	24.44**	10.73**	5.56	7.75**	20.87**	7.83**	4.45	3.97*	8.80**	6.54
102-8-5-1×2-1	0.81	-51.50**	-48.57**	-58.46	0.92	-51.32**	-47.43**	-55.99	4.37	-14.15**	-8.77**	-20.80	4.99	-10.41**	3.85	-3.23	4.26	9.23**	10.08**	1.99
115-1-8-1×58-18-1-1	1.34	3.08	22.94*	-31.28	1.77	25.53**	28.73**	-15.33	5.81	13.26**	15.39**	5.30**	5.96	34.54**	47.16**	15.59**	4.81	12.91**	15.21**	15.16**
115-1-8-1×55-26-1-1	1.46	65.91**	98.64**	-25.13	1.68	25.37**	62.32**	-19.63	6.57	28.07**	34.91**	19.07**	6.49	46.50**	50.06**	25.86**	4.56	-3.59*	3.40*	9.17
115-1-8-1×7-5-1	0.75	-28.57**	-22.28	-61.54	1.12	-18.84**	-17.65*	-46.42	5.82	13.45**	18.05**	5.48**	6.16	19.38**	28.47**	19.46**	4.3	0.47	2.75	2.95
115-1-8-1×2-1	2.00	19.76**	56.86**	2.56	2.23	17.99**	38.08**	6.68	4.67	-8.97**	-2.91	-15.36	5.82	4.49	16.40**	12.87**	4.24	3.67	6.94**	1.51
58-18-1-1×55-26-1-1	0.93	-13.08	12.05	-52.31	1.45	29.46**	56.76**	-30.64	5.56	20.61**	23.42**	0.77	5.91	23.90**	31.48**	14.62**	4.43	-17.50**	-12.28**	6.06
58-18-1-1×7-5-1	1.71	59.81**	61.32**	-12.31	1.88	36.23**	50.40**	-10.07	5.47	15.64**	19.82**	-0.86	5.22	1.16	5.14*	1.23	4.05	-24.58**	-16.06**	-3.04
58-18-1-1×2-1	1.2	-28.14**	-19.19	-38.46	1.37	-27.51**	-16.97**	-34.46	5.35	8.30**	13.47**	-3.04	5.28	-5.21*	14.29**	2.40	4.95	16.20**	22.22**	18.51**
55-26-1-1×7-5-1	0.87	-17.14**	6.10	-55.38	1.21	-12.32	14.69	-42.12	4.54	-4.02*	-2.78	-17.72	4.02	-22.09**	-14.29**	-22.04	3.33	-29.60**	-26.08**	-20.27
55-26-1-1×2-1	1.53	-8.38	35.40**	-21.54	1.69	-10.58	29.01**	-19.16	4.62	0.22	1.54	-16.27	3.87	-30.52**	-20.94**	-24.95	4.8	1.48	12.02**	14.92**
7-5-1×2-1	1.22	-26.95**	-10.29	-37.44	1.97	4.23	20.49*	-5.76	4.29	-9.30**	-6.94**	-22.25	4.67	-16.16**	-12.95**	-9.43	4.55	6.31**	12.07**	8.93**
CD at 5%	0.95	14.56	22.75	7.52	0.88	12.66	15.74	6.97	1.02	4.01	3.72	2.94	0.85	4.52	4.57	3.36	0.69	3.52	3.22	3.03
CD at 1%	1.30	19.48	30.44	10.06	1.21	16.93	21.06	9.33	1.40	5.37	4.98	3.93	1.16	6.05	6.11	4.49	0.95	4.71	4.30	4.06

Table 2. Contd.

Hybrids	TSS (°Brix)				Lycopene (mg 100 g^{-1})				Number of locules				Percarp thickness (cm)				Fruit weight (g)			
		Percentage increase/decrease over				Percentage increase/decrease over				Percentage increase/decrease over				Percentage increase/decrease over				Percentage increase/decrease over		
	Mean	Better parent	Mid parent	NS-524	Mean	Better parent	Mid parent	NS-524	Mean	Better parent	Mid parent	NS- 524	Mean	Better parent	Mid parent	NS-524	Mean	Better parent	Mid parent	NS- 524
PC×58-11-1-1	3.8	-21.65**	-14.51**	-16.81	3.77	17.81**	31.59**	21.68**	3.84	-5.65	6.67*	5.84*	0.64	20.75**	64.10**	8.77**	62.03	-4.95	30.07**	-32.13
PC×56-14-7-1	4.58	-5.57**	1.78	0.27	3.32	-12.17*	-4.87	7.16	3.94	25.88**	50.10**	8.59**	0.35	-40.68**	-37.50**	-40.52	51.03	69.42**	70.16**	-44.17
PC×102-13-6-1	3.89	-19.79**	-8.36**	-14.84	3.4	6.25	35.46**	9.74**	2.64	-31.25**	-24.25**	-27.24**	0.61	15.09**	15.09*	3.67	55.87	-20.73**	11.07*	-38.87
PC×102-1-6-1	3.9	-19.59**	-14.38**	-14.62	3.48	8.75	31.57**	12.32**	2.89	-32.48**	-22.00**	-20.35**	0.48	-17.24**	-13.51*	-18.42	73.37	-37.37**	-0.35	-19.73
PC×102-8-5-1	4.65	-4.12*	4.03*	1.80	3.02	-19.03**	-12.84*	-2.52	2.55	-18.53**	-2.49	-29.72**	0.32	-39.62**	-37.25**	-45.62	60.03	-2.99	30.50**	-34.32
PC×115-1-8-1	4.45	-8.25**	-3.16	-2.58	1.74	-62.74**	-55.78**	-43.84	3	-4.15	-2.12	-17.31**	0.63	18.87**	43.18**	7.07*	85.62	80.90**	121.10**	-6.32
PC×58-18-1-1	4.73	-2.47	5.82**	3.55*	2.64	-17.50**	1.54	-14.79	3.59	-1.10	6.21	-1.05	0.66	-14.29**	1.54	12.17**	57.57	-12.49*	20.05**	-37.01
PC×55-26-1-1	4.22	-12.99**	-7.76**	-7.61	2.16	-32.50**	-29.06**	-30.28	3.25	1.25	2.52	-10.42**	0.78	47.17**	47.17**	32.56**	52.84	-31.26**	-1.22	-42.19
PC×7-5-1	4.04	-16.70**	-9.32**	-11.55	3.08	-3.75	27.54**	-0.59	2.46	-30.11**	-26.02**	-32.20**	0.30	-43.40**	-38.14**	-49.02	51.62	-23.94**	5.36	-43.52
PC×2-1	4.19	-14.31**	-13.96**	-8.27	3.74	-5.56	4.47	20.72**	4.3	37.38**	43.09**	18.52**	0.59	11.32*	12.38*	0.27	44.44	-25.20**	-0.73	-51.38
58-11-1-1 ×56-14-7-1	4.53	9.16**	10.62**	-0.83	2.65	-29.89**	-16.01**	-14.47	3.79	-6.88**	22.46**	4.46	0.67	13.56**	59.52**	13.87**	56.97	-12.70*	19.79**	-37.67
58-11-1-1×102-13-6-1	4.37	8.17**	13.80**	-4.33	1.67	-33.99**	-23.22**	-46.10	3.81	-6.39*	-3.67	5.01	0.39	-26.42**	0.00	-33.72	122.6	73.95**	80.64**	34.14**
58-11-1-1×102-1-6-1	3.75	-11.97**	-9.64**	-17.90	1.75	-30.83**	-24.24**	-43.52	3.36	-21.50**	-19.52**	-7.39**	0.75	29.31**	80.72**	27.46**	72.53	-38.08**	-20.47**	-20.65
58-11-1-1×102-8-5-1	4.2	2.69	3.32*	-8.05	2.68	-28.15**	-14.38**	-13.50	2.73	-32.92**	-11.51**	-24.76**	0.69	40.82**	86.49**	17.27**	74.7	14.47**	17.51**	-18.27
58-11-1-1×115-1-8-1	4.45	2.53	6.21**	-2.58	3.08	-34.05**	-14.44**	-0.59	4.75	16.71**	34.37**	30.92**	0.65	85.71**	116.67**	10.47**	115.86	77.54**	105.81**	26.76**
58-11-1-1×58-18-1-1	4.15	1.47	2.09	-9.15	2.21	-12.65**	-2.43	-28.67	3.82	-6.14*	-0.78	5.29*	0.61	-20.78**	19.61**	3.67	104.2	58.38**	59.02**	14.00**
58-11-1-1×55-26-1-1	4.17	-3.02	0.00	-8.71	4.69	62.28**	73.06**	51.38**	3.59	-11.79**	-1.37	-1.05	0.6	13.21**	53.85**	1.97	68.7	-10.63*	-3.33	-24.84
58-11-1-1×7-5-1	3.7	-8.87**	-8.64**	-19.00	3.25	28.46**	56.25**	4.90	3.43	-15.72**	-9.62**	-5.46*	0.64	45.45**	85.51**	8.77**	89.7	32.16**	34.76**	-1.86
58-11-1-1x2-1	4.18	-14.52**	-6.38**	-8.49	1.96	-50.51**	-39.60**	-36.74	2.63	-35.38**	-24.32**	-27.51**	0.37	-28.85**	-3.90	-37.12	72.53	11.14*	16.36**	-20.65
56-14-7-1×102-13-6-1	4.47	7.71**	14.76**	-2.14	3.48	-7.94	24.29**	12.32**	3.46	-9.90**	16.11**	-4.64	0.58	-1.69	3.57	-1.43	56.96	-19.18**	13.53*	-37.68
56-14-7-1×102-1-6-1	4.56	7.04**	8.44**	-0.17	3.77	-0.26	28.45**	21.68**	2.79	-34.81**	-12.81**	-23.10**	0.40	-32.20**	-31.62*	-32.02	52.79	-54.93**	-28.18**	-42.24
56-14-7-1×102-8-5-1	4.33	4.34*	5.10**	-5.20	3.7	-2.12	-1.46	19.42**	3.12	47.17**	47.87**	-14.01**	0.53	-10.17**	-1.85	-9.93	48.96	-20.88**	6.74	-46.43
56-14-7-1×115-1-8-1	3.99	-8.06**	-6.01**	-12.65	3.38	-27.62**	-20.00**	9.10*	2.35	-21.67**	-8.20*	-35.23**	0.57	-3.39**	21.28**	-3.13	44.83	-5.28	16.15**	-50.95
56-14-7-1×58-18-1-1	3.9	-6.02**	-5.34**	-14.62	4.99	32.01**	72.66**	61.06**	2.85	-21.49**	-0.87	-21.45**	0.5	-35.06**	-26.47**	-15.03	76.1	15.67**	59.12**	-16.74
56-14-7-1×55-26-1-1	3.89	-9.53**	-7.93**	-14.84	4.78	26.46**	43.33**	54.28**	2.35	-26.79**	-11.82**	-35.23**	0.63	6.78	12.50*	7.07*	82.58	7.43	54.75**	-9.65
56-14-7-1×7-5-1	3.69	-14.19**	-12.66**	-19.22	4.04	6.88	21.14**	30.40**	3.3	2.80	23.83**	-9.05**	0.58	-1.69	3.57	-1.43	55.83	-27.37**	4.62	-38.92
56-14-7-1×2-1	3.8	-22.29**	-15.93**	-16.81	2.1	-46.97**	-45.74**	-32.22	2.2	-23.61**	-12.00**	-39.36**	0.38	-35.59**	-31.53**	-35.42	30.66	-48.39**	-31.31**	-66.46
102-13-6-1×102-1-6-1	3.39	-20.42**	-14.18**	-25.78	3.05	45.93**	56.01**	-1.56	2.58	-39.72**	-36.45**	-28.89**	0.41	-29.31**	-26.13**	-30.32	62.43	-46.70**	-33.45**	-31.70
102-13-6-1×102-8-5-1	3.74	-8.56**	-3.23	-18.12	4.89	31.10**	76.22**	57.83**	3.26	-15.10**	9.76**	-10.15**	0.35	-33.96**	-31.37**	-40.52	90.66	28.63**	36.99**	-0.81
102-13-6-1×115-1-8-1	3.34	-23.04**	-16.29**	-26.88	3.57	-23.55**	10.02	15.23**	2.59	-32.55**	-24.27**	-28.61**	0.51	-3.77	15.91**	-13.33	83.99	19.17**	42.59**	-8.11
102-13-6-1×58-18-1-1	4.37	6.85**	13.07**	-4.33	2.82	41.00**	47.64**	-8.98	5.13	33.59**	37.35**	41.39**	0.79	2.60	21.54**	34.26**	99.29	40.88**	45.73**	8.63*
102-13-6-1×55-26-1-1	3.89	-9.53**	-2.02	-14.84	3.99	38.06**	69.43**	28.79**	3.79	-1.30	7.52*	4.46	0.65	22.64**	22.64**	10.47**	92.79	20.71**	25.95**	1.52
102-13-6-1×7-5-1	4.29	5.67**	11.43**	-6.08	3.9	114.29**	126.09**	25.88**	3.93	2.34	6.79*	8.32**	0.50	-5.66	3.09	-15.03	89.46	26.93**	29.32**	-2.12
102-13-6-1×2-1	5.13	4.91**	20.28**	12.31**	2.26	-42.93**	-21.80**	-27.05	3.13	-18.49**	-6.85*	-13.73**	0.57	7.55	8.57	-3.13	36.12	-48.75**	-44.38**	-60.48
102-1-6-1×102-8-5-1	4.52	6.10**	8.26**	-1.04	3.07	-17.69**	5.50	-0.91	3.13	-26.87**	-1.88	-13.74**	0.41	-29.31**	-23.36**	-30.32	64.46	-44.97**	-27.99**	-29.48
102-1-6-1×115-1-8-1	4.35	0.23	1.16	-4.77	3.63	-22.27**	7.40	17.17**	1.99	-53.50**	-45.33**	-45.15**	0.59	1.72	26.88**	0.27	78.14	-33.29**	-4.98	-14.51
102-1-6-1×58-18-1-1	5.45	27.93**	30.54**	19.32**	3.28	56.94**	60.39**	5.87	3.48	-18.69**	-12.01**	-4.08	0.53	-31.17**	-21.48**	-9.93	95.48	-18.49**	4.39	4.46

Table 2. Contd.

102-1-6-1×55-26-1-1	4.24	-1.40	-0.93	-7.17	3.87	33.91**	55.42**	24.91**	3.23	-24.53**	-13.75**	-10.97**	0.47	-18.97**	-15.32*	-20.12	102.98	-12.09*	6.16	12.67**
102-1-6-1×7-5-1	3.94	-7.51**	-5.29**	-13.74	2.81	34.45**	51.08**	-9.30	2.31	-46.03**	-40.77**	-36.33**	0.50	-13.79**	-1.96	-15.03	73.81	-36.99**	-20.21**	-19.25
102-1-6-1×2-1	4.54	-7.16**	-0.77	-0.61	4.13	4.29	36.53**	33.30**	3.35	-21.73**	-6.42	-7.67**	0.45	-22.41**	-18.18**	-23.52	50.48	-56.91**	-42.82**	-44.77
102-8-5-1×115-1-8-1	3.94	-9.22**	-6.52**	-13.74	3.74	-19.91**	-10.95*	20.72**	2.73	-9.00**	7.06*	-24.76**	0.67	36.73**	59.52**	13.87**	52.98	-14.38**	-2.98	-42.04
102-8-5-1×58-18-1-1	4.3	5.13**	5.13**	-5.86	4.82	29.22**	68.24**	55.58**	3.28	-9.64**	14.49**	-9.60**	0.44	-42.86**	-30.16**	-25.22	60.48	-8.07	-5.26	-33.83
102-8-5-1×55-26-1-1	4.4	2.33	4.89**	-3.67	3.68	-1.34	11.18*	18.78**	4.64	44.55**	74.76**	27.89**	0.38	-28.30**	-25.49**	-35.42	83.81	9.03	20.81**	-8.30
102-8-5-1×7-5-1	3.98	-2.69	-2.33	-12.87	3.17	-15.01**	18.28**	2.32	2.87	-18.47**	2.14	-20.90**	0.67	36.73**	44.09**	13.87**	108.53	59.91**	67.29**	18.74**
102-8-5-1×2-1	3.05	-37.63**	-32.07**	-33.23	3.21	-18.94**	-16.51**	3.61	2.56	-11.11**	2.81	-29.44**	0.53	1.92	4.95	-9.93	56.87	-8.10	-6.22	-37.78
115-1-8-1×58-18-1-1	5.36	23.50**	27.16**	17.35**	2.11	-54.82**	-36.73**	-31.90	3.71	2.20	11.92**	2.26	0.74	-3.90	32.14**	25.76**	106.87	62.44**	88.95**	16.93**
115-1-8-1×55-26-1-1	4.38	0.92	1.39	-4.11	3.75	-19.70**	-0.79	21.04**	3.21	0.00	3.38	-11.53**	0.70	32.08**	59.09**	18.96**	115.2	49.86**	85.51**	26.04**
115-1-8-1×7-5-1	4.1	-5.53**	-2.38	-10.24	3.52	-24.63**	11.75*	13.62**	4.43	25.85**	35.89**	22.10**	0.63	43.18**	59.49**	7.07*	104.37	53.78**	81.20**	14.19**
115-1-8-1×2-1	3.1	-36.61**	-32.83**	-32.13	1.36	-70.88**	-68.48**	-56.10	2.6	-13.33**	-11.56**	-28.34**	0.38	-26.92**	-12.64**	-35.42	58.53	-1.48	9.67	-35.96
58-18-1-1×55-26-1-1	3.95	-8.14**	-5.28**	-13.52	2.63	-9.00	-2.95	-15.11	3.93	-3.44	7.97*	8.32**	0.88	66.04**	125.64**	49.56**	77.57	0.91	9.15	-15.13
58-18-1-1×7-5-1	4.41	8.62**	8.89**	-3.45	2.72	7.51	30.77**	-12.21	2.87	-29.48**	-24.37**	-20.90**	0.76	72.73**	120.29**	29.16**	78.53	15.71**	17.97**	-14.08
58-18-1-1×2-1	4.21	-13.91**	-6.24**	-7.83	2.94	-25.76**	-1.34	-5.11	4.01	10.47**	23.20**	10.52**	0.60	-22.08**	-6.98	1.97	74.95	13.92**	19.73**	-18.00
55-26-1-1×7-5-1	4.64	7.91**	11.00**	1.58	2.16	-25.26**	-4.42	-30.28	2.88	-18.18**	-14.41**	-20.62**	0.35	-33.96**	-27.84**	-40.52	48.29	-37.18**	-33.27**	-47.17
55-26-1-1×2-1	3.94	-19.43**	-14.25**	-13.74	2.82	-28.79**	-17.66**	-8.98	3.79	18.07**	24.47**	4.46	0.48	-9.43*	-8.57	-18.42	44.29	-42.38**	-35.00**	-51.54
7-5-1×2-1	4.25	-13.09**	-5.03**	-6.96	2.91	-26.52**	4.11	-6.07	2.45	-30.40**	-23.44**	-32.47**	0.40	-23.08**	-16.67**	-32.02	28.29	-58.32**	-55.55**	-69.05
CD at 5%	0.53	3.42	3.30	2.76	1.66	9.38	10.40	7.51	1.01	6.02	6.46	5.19	0.31	8.57	11.57	6.38	36.79	10.36	10.73	6.82
CD at 1%	0.75	4.58	4.41	3.69	2.28	12.56	13.92	10.05	1.39	8.06	8.64	6.94	0.43	11.46	15.48	8.54	50.46	13.86	14.36	9.12

*, ** significant at 5 and 1% level, respectively.

Equatorial diameter (cm)

Four cross combination, that is, Punjab Chhuhara × 2-1, 102-8-5-1 × 7-5-1, 102-13-6-1 × 115-1-8-1, 58-11-1-1 × 58-18-1-1 and 115-1-8-1 × 55-26-1-1, were identified as promising for equatorial diameter. These crosses outperformed the resistant check NS 524 by 9.10, 10.73, 11.10, 11.28 and 19.07%, respectively. Kumar et al. (2006), Ahmad et al. (2011) and Shende et al. (2012) reported heterotic hybrids for equatorial diameter.

Polar diameter (cm)

The potential tomato fruit shape and size depend on cell number established in pre-anthesis stage but the final fruit size depends on the rate and duration of cell enlargement. Seed number and competition among fruits also affect the final fruit shape. Five cross combinations *viz*., 115-1-8-1 × 58-18-1-1, 115-1-8-1 × 7-5-1, 115-1-8-1 × 55-26-1-1, 58-11-1-1 × 56-14-7-1 and 102-1-6-1 × 115-1-8-1, were identified promising for polar diameter and outperformed the resistant check NS-524 by 15.59, 19.46, 25.86, 27.42 and 32.07%, respectively. Ahmad et al. (2011) and Shende et al. (2012) reported significantly positive heterosis for this trait.

Dry matter (%)

The importance of fruit dry matter content is well recognized for the preparation of various products made from tomato. The cross combinations namely, 56-14-7-1 × 102-1-6-1, 115-1-8-1 × 58-18-1-1, 102-1-6-1 × 55-26-1-1, 58-11-1-1 × 115-1-8-1 and Punjab Chhuhara × 58-18-1-1, were identified as promising for dry matter and outperformed the resistant check by 24.98, 15.16, 18.03, 38.14 and 48.89%, respectively. Significant heterosis for dry matter was earlier reported by Gaikwad et al. (2009) and Garg and Cheema (2011).

Total soluble solids (°Brix)

The major constituents of TSS are glucose, fructose and sucrose. These parameters are of major interest of the processing industries as cultivars with high soluble solids give more finished product per unit weight of raw fruit. Three cross combinations exhibited significant heterosis over NS-524. The cross combinations, that is, 102-13-6-1 × 2-1, 115-1-8-1 × 58-18-1-1 and 102-1-6-1 × 58-18-1-1, were identified as promising for total soluble solids and outperformed the resistant check NS-524 by 12.31, 17.35 and 19.32%, respectively. Heterosis for this trait was also observed by Gunasekera and Parera (1999), Anitha et al. (2007), Sharma and Thakur (2008) and Dod et al. (1995). However, Wang et al. (1998) noticed that hybrids were intermediate between their parents for total soluble solids.

Lycopene content (mg 100 g^{-1})

Increased lycopene content has proven nutritional value as an antioxidant, which is associated with a low incidence of certain forms of human cancer. Recently, high-lycopene tomatoes have been sold as specialties in the fresh market. High lycopene content imparts dark red colour to the tomato, which is preferred for table as well as processing purpose. The hybrid combinations, that is, 58-11-1-1 × 55-26-1-1, 102-13-6-1 × 102-8-5-1, 102-8-5-1 × 58-18-1-1, 56-14-7-1 × 55-26-1-1 and 56-14-7-1 × 58-18-1-1, were identified as promising for lycopene content. These crosses outperformed the resistant check NS-524 by 51.38, 57.83, 55.58, 54.28 and 61.06%, respectively. Gaikwad et al. (2009) reported significant heterosis for lycopene content.

Number of locules per fruit

The locular proportion of tomato fruit contains more organic acids and less reducing sugars than the pericarp portion (Grierson and Kader, 1986). Locule number is also important from the fruit firmness point of view. Lesser the number of locules per fruit more is the fruit firmness and the *vice versa*. Four cross combinations, that is, 115-1-8-1 × 2-1, Punjab Chhuhara × 7-5-1, 56-14-7-1 ×115-1-8-1 and 102-1-6-1 × 115-1-8-1, were identified as promising for number of locules per fruit and desirable heterosis over the resistant check. Heterosis by these hybrids over the commercial check NS-524 was worked out to be -26.92, -32.20, -35.23 and -45.15%, respectively. Sundram et al. (1994), Srivastava et al. (1998), Anitha et al. (2007) also reported heterosis for locule number. Significant negative heterosis for number of locules per fruit was also reported by Singh et al. (2005).

Pericarp thickness (cm)

Thicker pericarp is another trait that imparts fruit firmness and is, therefore considered desirable for processing and distant transportation. Five cross combinations *viz*., 115-1-8-1 × 58-18-1-1, 58-11-1-1 × 102-1-6-1, Punjab Chhuhara × 55-26-1-1, 102-13-6-1 × 58-18-1-1 and 58-18-1-1 × 55-26-1-1, were identified as promising for pericarp thickness. These crosses outperformed the resistant check NS-524 by 25.76, 27.46, 32.56, 34.26 and 49.56%, respectively. Cheema et al. (1996), Tiwari and Lal (2004) and Sharma and Thakur (2008) reported positive heterosis for pericarp thickness.

Average fruit weight (g)

Fruit weight directly contributes towards total yield and serves as an important factor for consumer preference and for processing suitability. Cultivars are classified based on their fruit size and shape from the cherry tomato (<20 g) to beef tomato (fruit weight > 200 g). Three cross combinations namely, 115-1-8-1 × 55-26-1-1, 58-11-1-1 × 115-1-8-1 and 58-11-1-1 × 102-13-6-1 showed highly significant and positive heterosis over NS-524. These crosses outperformed the resistant check NS-524 by 26.04, 26.75 and 34.14%, respectively. The heterosis for fruit weight was also reported by Sharma and Thakur (2008).

Screening of parents and hybrids for TLCV resistance

The data related to screening for TLCV under field conditions are given in Table 3. The parent 2-1 did not show any disease symptoms throughout the growth period under natural conditions where as Punjab Chhuhara and 102-1-6-1 showed severe disease infection. Of the remaining eight lines, seven showed mild and one showed moderate infection. Mild symptoms of TLCV were exhibited by the lines 58-11-1-1, 56-14-7-1, 102-13-6-1, 102-8-5-1, 115-1-8-1, 55-26-1-1 and 7-5-1, whereas, 58-18-1-1 showed moderate infection. In general, it was observed that the genotypes, which showed early appearance of TLCV, resulted in severe yield losses as compared to the genotypes which showed late appearance of TLCV.

It was observed that out of fifty-five cross combinations, seventeen crosses were completely free from TLCV. Twenty-three cross combinations showed mild infection, thirteen moderate infection and two were susceptible. Tomato germplasm/hybrids were extensively screened by Rattan and Bindal (2002), Shekara et al. (2003), Castro et al. (2007) and Mazyad et al. (2007), and reported differential response of genotypes/hybrids against TLCV.

Significant differences that emerged from tomato hybrids on the incidence of disease could possibly be attributed to the fact that the whiteflies had affinity with some particular accessions than the other accessions

Table 3. Screening of tomato parents and hybrids against TLCV disease under field conditions.

S/N	Genotype	Reaction to TLCV
Parents		
1	Punjab Chhuhara (PC)	S
2	58-11-1-1	M
3	56-14-7-1	M
4	102-13-6-1	M
5	102-1-6-1	S
6	102-8-5-1	M
7	115-1-8-1	M
8	58-18-1-1	Mo
9	55-26-1-1	M
10	7-5-1	M
11	2-1	R
Crosses		
1	Punjab Chhuhara × 58-11-1-1	Mo
2	Punjab Chhuhara × 56-14-7-1	S
3	Punjab Chhuhara × 102-13-6-1	Mo
4	Punjab Chhuhara × 102-1-6-1	Mo
5	Punjab Chhuhara × 102-8-5-1	M
6	Punjab Chhuhara × 115-1-8-1	Mo
7	Punjab Chhuhara × 58-18-1-1	Mo
8	Punjab Chhuhara × 55-26-1-1	M
9	Punjab Chhuhara × 7-5-1	M
10	Punjab Chhuhara ×2-1	Mo
11	58-11-1-1 × 56-14-7-1	M
12	58-11-1-1 × 102-13-6-1	Mo
13	58-11-1-1 × 102-1-6-1	M
14	58-11-1-1 × 102-8-5-1	M
15	58-11-1-1 × 115-1-8-1	R
16	58-11-1-1 × 58-18-1-1	R
17	58-11-1-1 × 55-26-1-1	R
18	58-11-1-1 × 7-5-1	R
19	58-11-1-1 × 2-1	M
20	56-14-7-1 × 102-13-6-1	M
21	56-14-7-1× 102-1-6-1	Mo
22	56-14-7-1× 102-8-5-1	M
23	56-14-7-1× 115-1-8-1	M
24	56-14-7-1× 58-18-1-1	R
25	56-14-7-1× 55-26-1-1	R
26	56-14-7-1× 7-5-1	R
27	56-14-7-1× 2-1	R
28	102-13-6-1 × 102-1-6-1	R
29	102-13-6-1 × 102-8-5-1	Mo
30	102-13-6-1 × 115-1-8-1	M
31	102-13-6-1 × 58-18-1-1	Mo
32	102-13-6-1 × 55-26-1-1	R
33	102-13-6-1 × 7-5-1	M
34	102-13-6-1 × 2-1	R
35	102-1-6-1× 102-8-5-1	M
36	102-1-6-1× 115-1-8-1	Mo

Table 3. Contd.

37	102-1-6-1× 58-18-1-1	M
38	102-1-6-1× 55-26-1-1	M
39	102-1-6-1× 7-5-1	M
40	102-1-6-1× 2-1	S
41	102-8-5-1× 115-1-8-1	R
42	102-8-5-1× 58-18-1-1	M
43	102-8-5-1× 55-26-1-1	M
44	102-8-5-1× 7-5-1	R
45	102-8-5-1×2-1	Mo
46	115-1-8-1×58-18-1-1	R
47	115-1-8-1×55-26-1-1	R
48	115-1-8-1×7-5-1	M
49	115-1-8-1×2-1	R
50	58-18-1-1×55-26-1-1	M
51	58-18-1-1×7-5-1	R
52	58-18-1-1×2-1	M
53	55-26-1-1×7-5-1	Mo
54	55-26-1-1×2-1	M
55	7-5-1×2-1	M
	Checks	
1	NS-524	M

R, Resistant; M, mild Infection; Mo- moderate Infection; S- severe infection.

and resulted in some hybrids being more susceptible to virus than the other accessions. The accessions that had less number of infected plants could be explained by late occurrence of TLCV infection related to whitefly population variation. Moreover, this difference in reaction could be due to the virus strain, vector genotype or altered feeding conditions of the vector.

These genotypes were further used in the breeding programme for the development of tomato cultivars/hybrids resistant to TLCV.

Conclusion

Heterosis was observed for all the characters studied. The minimum heterosis was exhibited for equatorial diameter, whereas, the maximum hetrsosis was exhibited for marketable yield (over MP, BP and check). For fruit weight, nineteen and seven hybrids exhibited significantly positive heterosis over BP and NS 524, respectively. The best performing cross was 58-11-1-1 × 102-13-6-1 exhibiting 73.95 and 34.14% heterosis over better parent and NS-524, respectively. For total fruit yield, twenty-three and four hybrids exhibited significantly positive heterosis over BP and NS-524, respectively. The best performing cross combination was 102-13-6-1 × 2-1 with 80.42 and 63.12% heterosis over better parent and NS-524, respectively. The cross combination 58-18-1-1 × 55-26-1-1 (0.88 cm) exhibited maximum pericarp thickness. The hybrid showed 66.04 and 49.56% heterosis over the better parent and NS-524, respectively for pericarp thickness. The cross combination 102-1-6-1 × 115-1-8-1 recorded the minimum number of locules per fruit. The hybrid exhibited 53.50 and -45.15% heterosis over better parent and NS-524, respectively. The cross combination 102-1-6-1 × 58-18-1-1 exhibited maximum heterosis for total soluble solids. The hybrid exhibited 27.93 and 19.32% heterosis over better parent and NS-524, respectively. The cross combination 56-14-7-1 × 58-18-1-1 exhibited maximum heterosis (61.06%) over NS-524 for lycopene content. The cross combination Punjab Chhuhara × 58-18-1-1 exhibited maximum heterosis of 43.89% over NS-524 for dry matter content. The cross combination 102-1-6-1 × 115-1-8-1 exhibited maximum heterosis of 32.07% over NS-524 for polar diameter. In case of equatorial diameter, the cross combination 115-1-8-1 × 55-26-1-1 exhibited the maximum hetrosis of 19.07% over NS-524. The lines showing minimum or no symptoms of TLCV disease under natural field conditions and mild disease infection under artificial inoculation conditions could be used to breed true breeding lines or commercial F_1 hybrids tolerant to TLCV. The best performing hybrids include 102-13-6-1 × 2-1 for marketable yield (3.24 kg plant^{-1}), Punjab Chhuhara × 58-18-1-1 for dry matter content 6.01%), 58-11-1-1 × 102-13-6-1 for fruit weight (122.60g), 102-1-6-1 × 115-1-8-1 for number of locules (1.99), 56-14-7-1 × 58-18-1-1 for lycopene content (4.99 mg/100g), 102-1-6-1 × 58-18-1-1 for TSS content (5.45°Brix), 58-18-1-1×55-26-1-1 for pericarp thickness (0.88 cm), 102-1-6-1 × 115-1-8-1 for polar diameter (6.81 cm) and 115-1-8-1 × 55-26-1-1 for equatorial diameter (6.57 cm).

Four cross combinations with resistance to TLCV, namely 102-8-5-1 × 7-5-1, 102-13-6-1 × 55-26-1-1, 58-11-1-1 × 58-18-1-1 and 102-13-6-1 × 2-1, were identified as promising. These hybrids recorded fruit yield of 2.22, 2.29, 2.70 and 3.24 kg plant^{-1}. Their yield performance was either at par or significantly higher than the resistant check NS 524 (1.95 kg plant^{-}1). These hybrids need to be confirmed over years and locations for before recommending these for commercial cultivation.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Poverty experienced by crop farmers in crude oil polluted areas of Rivers State, Nigeria using socio-economic variables

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Poverty experienced by crop farmers' households in crude oil polluted areas of Rivers State, Nigeria was determined using socio-economic variables. Data were collected by multistage sampling technique and a total of 296 questionnaires were analysed. Results of crop farming experience showed that there was higher level of incidence of poverty (P_0 = 63.8%) among crude oil polluted crop farmer households as compared to P_0 = 52% in non-polluted and P_0 = 58.2% in all crop farmer households surveyed in the state, significant at 1%. There were more headcount poverty (P_0 = 65.3%) among crude oil polluted crop farmer households than among non-polluted (P_0 = 49.7%) and in all crop farmer households surveyed (P_0 = 56.4%) using household heads membership to cooperative societies (significant 1%). None membership of cooperative society contributed 80% of overall poverty. There was more poverty experienced at P_0, P_1 and P_2 measures in households without other working members which contributed 57.8 to 63.8% of overall poverty. The poverty experienced among crude oil polluted crop farmer households (P_0 = 65.9%) was higher than in non-polluted (P_0 = 52.8%) and P_0 = 57.3% in all households surveyed using other working members. The study found out that the reason for higher level of headcount poverty experienced among crude oil polluted crop farmer households was due to the presence of crude oil pollution on their crop farms. Therefore, crude oil pollution increased poverty level of crop farmers in Rivers State, Nigeria.

Key words: Poverty, farming experience, cooperatives membership, working members, oil pollution, Nigeria.

INTRODUCTION

Crude oil pollution damage the fertility of soil and vegetation, destroy wild life and breeding ground for marine fishes, because of the toxicity of oil, thereby making farming, fishing and hunting difficult for the inhabitants of the area (Onwuka, 2005; Chikere et al., 2009). Therefore, crude oil pollution in the Niger Delta region causes severe socio-economic and environmental impacts. The impacts of the crude oil pollution occur at the local, national, regional and global levels (Platform, 2012). At all levels it is the poor that bear the heaviest burden. UNEP (2011) report on Ogoni land showed that crude oil pollution from 50 years of oil operations in the Niger Delta region of Nigeria has penetrated further and deeper than many may have supposed.

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In some areas, which appear unaffected at the surface, were in reality severely contaminated underground. Where entrepreneurs have established fish farms in the region, their businesses had been ruined by an "ever-present" layer of floating oil. Crude oil pollution therefore, impoverishes the inhabitants of the Niger Delta region of Nigeria (UNEP Report, 2011; Platform, 2012). The Niger Delta region includes the following nine states of the Federal Republic of Nigeria: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers State.

Problem of the study

Osuji and Nwoye (2007) observed that the impact of petroleum hydrocarbon on soil fertility included low soil fertility, which in turn implied low agricultural productivity and reduced source of livelihood in the affected area. Oil spills have become a major environmental hazard constituting serious socio-economic problems in Nigeria, especially in the oil producing communities (Atakpo and Ayolabi, 2009).

Idemudia (2008) assessed the issue of community development partnership and poverty reduction in the Niger Delta by oil transnational corporations. The paper found out that the community development partnership with the multinational oil companies had very limited positive impacts on poverty reduction in the region. Orogun (2009) in a case study illustrated and explicated the paradox of plenty, the resource course, the shadow state syndrome, and the debilitating effects of petroleum politics, in Nigeria. Economic exploitation of the region's vast crude oil reserves by multinationals and governments and government authorities is juxtaposed, with the specter of environmental devastation excruciating poverty, and the recurrent rule of impunity.

Therefore, the problem of this study is to measure and compare poverty levels among crop farmers in crude oil polluted and non-polluted areas in Rivers State, Nigeria using socio-economic variables. The socio-economic variables considered in this study include years of farming experience, other working members of the household and membership of co-operative society. These variables were used to estimate and compare poverty levels using Foster et al. (1984) poverty measures of headcount, poverty gap and severity respectively in decomposable forms.

Significance of the study

Previous studies in the use of social and economic variables to describe the effects of crude oil pollution on the populace in Niger Delta abounds (Eweje, 2006; Edino et al., 2010; Efe, 2010). Literature exist in the use of socio-economic variables in determining the poverty levels among crop farmers (Thorp et al., 2005; Nasution, 2008).

Eweje (2006) examined issues of environmental costs and responsibilities resulting from oil exploitation and production in the Niger Delta region of Nigeria. The article further examined the implication of the current practices and policies of the multinational oil companies with respect to environmental impact of oil exploitation. The study's findings illustrated that it is apparent to oil companies that pollution prevention pays while pollution does not.

Edino et al. (2010) observed that many studies had established relationships between gas flaring and poor agricultural yields. Their study found that the residents perceived gas flaring as hazardous to health, environment and general well-being of the community. Most residents seem to be resigned to the continued presence of gas flaring activities in the community.

Thorp et al. (2005) reported that group formation has great potential to empower and raise the incomes of poor people. According to the study, chronically poor are disadvantaged in group formation and this may form a significant part of vicious circle and dynamics of chronic poverty. Successful groups formed among the poor according to the study often exclude the even poorer, particularly those associated with market functions. It is the political function of groups that is of primary importance in helping to overcome marginalization and social exclusion experienced by the poorest.

Nasution (2008) retrieved data from Indonesia's Central Board of Statistic. Primary data comprised of farm development by the government, rural poverty in each village, farmer experience in poverty alleviation, and heads of villages, field farm officials, farmer group units, and field observation. Regression model was developed with classical normal linear regression model to reveal each variables share on rural poverty. Therefore, none of these studies had studied the current topic of poverty measurement among crop farmers in crude oil polluted areas in Rivers State, Nigeria using socio-economic variables.

Objectives of the study

The main objective of this study is to measure and compare poverty existing in crop farmers households in crude oil polluted areas of Rivers State, Nigeria. The specific objectives are to:

(i) Measure and compare the level of poverty by years of farming experience among crop farmers' households in crude oil polluted and non-polluted areas of Rivers State, Nigeria.
(ii) Determine and compare the level of poverty by cooperative membership of crop farmer households heads in crude oil polluted and non-polluted areas of the state.
(iii) Analyze and compare the level of poverty by other working members of the households in crude oil polluted

and non-polluted crop farms in Rivers State.

(iv) Make suggestions on how poverty could be alleviated among crude oil polluted crop farmers' households in Rivers State, Nigeria.

LITERATURE REVIEW

Tsui (1996) studied a class of subgroup decomposable poverty measure whose changes may be decomposed into a growth and redistribution components. Bourguignon and Fields (1997) examined the distributional properties of poverty measures which are discontinuous, at the poverty line. It was shown that among all the additive poverty measure, only those measures with some discontinuous jump at the poverty line were such that it is optimal to allocate a given anti poverty budget either to the richest of the poor, or to the poorest of the poor, or to both. A special class of such poverty measures is an extension of the well known p , the properties of which were investigated by them. Adams and Page (2005) results showed that both international migration and remittances significantly reduce the level, depth and severity of poverty in the developing world. The results suggested that a 10% increase in the share of international migrants in a country's population will lead to a 2.1% decline in the share of people living on less than $1.00 per person per day. A similar 10% increase in per capita official international remittances will lead to a 3.5% decline in the share of people living in poverty.

Jolliffe et al. (2005) using a production survey from 1989 to 2001, considered the impact of food stamps on three measures of poverty - the headcount, the poverty gap and the squared poverty gap. They found that in comparison to the headcount measure, food stamp benefits led to large reduction in the poverty gap and squared poverty gap measure.

Dercon (2006) reported that a new decomposition of poverty changes was developed to analyze the determinants of poverty changes during a period of economic reform (1989 – 1995) in villages in Ethiopia. Poverty fell substantially, but with diverse experiences across villages. The farming experiences of the poor were mixed. One group of the poor in 1989, with relatively good land and location, out performed all other households, while another group with much poorer endowments and location experienced virtually unchanged and persistent poverty.

Babu and Sanyal (2009) in their work on food security, poverty and nutrition policy analyzed the measurement and determinants of poverty using logistic regression models. In their study they derived poverty line, poverty gap index and squared poverty gap index and other related variables. Gupta et al. (2009) assessed the effect of the steady growing remittance flows to sub-saharan Africa.

The study found that remittances which were a stable private transfer have a direct poverty mitigating effect, and promote financial development. Maertens and Swinnen (2009) compared the characteristics of households who did not participate at all in French bean production and processing (non-participants) in Senegal, households with one or more members employed in the French bean agro – industry (agro-industrial employed), and households producing French bean on contract (contract farmers) and found that there were substantial differences in their human, physical and social capital. More contracted farmers were members of a farmers' organization. They found out that export grew and contributed importantly to rural incomes and poverty reduction.

METHODOLOGY

Data collection

This study was conducted in Rivers State of Nigeria. The state is located in the southern part of the Niger Delta region of Nigeria and is blessed with abundance of natural resources including majority of Nigeria's crude oil and gas deposits (Ekpo, 1981; Osuji, 1998; Abii and Nwosu, 2009). Rivers State is characterized by two distinct seasons; wet and dry, which favour the cropping of cassava, yam, cocoyam, maize, oil palm, plantain, banana, vegetables, fruits etc.

Data was collected from both primary and secondary sources. The primary data were collected through personal interviews and observations with the farmers, and structured questionnaires distributed among farmers in crude oil polluted and non crude oil polluted areas of an affected community in the state. Data on socio-economic variables, household expenditure, area of farmland cultivated, area of farmland spilled or acquired for crude oil exploration, exploitation and production, value of crops lost, output, value of crops produced etc. formed the bulk of information generated.

A multistage sampling procedure was used to obtain data for this study. It is a known fact that crude oil production, exploitation and exploration activities are widespread throughout the 23 local government areas (LGAs) of the state. The first stage involved the selection of 17 LGAs out of the existing 23 LGAs in the state. These 17 LGAs were selected because they were more crop farming inclined than others. The second stage involved the stratification of farmland in an LGA into two sampling units such as crude oil polluted and non-crude oil polluted. This stratification of the farmland into two sampling units was based on the fact that information were needed from both crude oil polluted and non-polluted areas.

The third stage involved the random sampling of 10 crop farmers from crude oil polluted areas in a selected LGA and a corresponding number of 10 crop farmers from non-crude oil polluted farmland in the same locality (community) in the given LGA. This summed to 20 crop farmer households interviewed per selected LGA in Rivers State. Ten crop farmer households only were sampled for easy survey and enumeration during random sampling, cost effectiveness and ensuring that the differences in crop production in the number of crude oil polluted and non-polluted farmland in the different LGAs could easily be compared.

Therefore, a total of 340 questionnaires were distributed among crop farmer households in the 17 LGAs selected which included: Abua/Odual, Ahoada West, Ahoada East, Andoni, Asaritoru, Degema, Eleme, Emohua, Etche, Gokana, Ikwerre, Khana, Obio/Akpor, Ogba/Egbema/Ndoni, Omuma, Oyigbo and Tai LGAs. However, only a total of 296 questionnaires were retained as suitable for analysis. These 296 questionnaires retained for analysis consisted of 169 questionnaires from crude oil polluted crop farmer households, and 127 questionnaires from non-crude oil polluted crop farmer households.

Poverty measures

Ravallion (1992) on comparing the poverty measures for headcount (H) poverty gap (PG) and poverty severity (P_2) said a common structure was evident in them and suggested a generic class of additive measures as follows:

$$P\alpha = \frac{1}{n} \sum_{i=1}^{q} \left(\frac{z - yi}{z} \right)^{\alpha} \quad (1)$$

Where, $P\alpha$ = weighted poverty index, q = the number of crop farmer households in poverty, y_i = the per adult equivalent expenditure of crop farmer household, z= the poverty line, α = 0, 1, 2 (that is, the degree of concern for the depth of poverty in a household), n = number of crop farmer households surveyed. for some non-negative parameter α. This is the Foster – Greer – Thorbecke (FGT) class of poverty measures (Foster et al., 1984). $P\alpha$ is simply the mean over the whole population of an individual poverty measure which takes the value (1 – yi/z) α for the poor and zero for the non-poor.

The main poverty measures of the headcount index has α = o, while α = 1 is for PG and α = 2 is for P_2. For both the poverty gap index P_1 and P_2 the individual poverty measure is strictly decreasing in the living standard of the poor (the lower the standard of living the poorer you are deemed to be). Further, P_2 has the property that the increase in your measured poverty due to a fall in standard of living will be deemed greater the poorer you are. For easy computation, Equation (1) is equivalent to Equation (2) (Ravallion, 1992; Duclos et al., 2002):

$$P\alpha = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{z-yi}{z} \right) 1(\text{yi}\#\text{z}) \quad (2)$$

Where, N = total number of households surveyed (296 samples). I(.) = is an indicator variable which takes on a value of one if it's argument is true (that is, the household is poor) and zero otherwise (that is, the poverty gap of the non-poor is set to zero).

Thus, the estimate of $P\alpha$ is simply the average of the poverty gaps raised to the power α, where by definition, the poverty gaps of the non-poor are zero. Clearly, a nice feature of the FGT – class of poverty measures is its simplicity and the ease with which it is calculated.

RESULTS

The socio-economic variables used in considering poverty experienced in this study were farming experience of household heads, their co-operative membership and other working members of the households.

Poverty measures by years of farming experience

The measures of poverty by years of farming experience of household heads in crop production in Rivers State, Nigeria are given in Table 1. The table shows the result of years of farming experience in all farms surveyed in Rivers State, crude oil polluted and non-polluted crop farms respectively. In all crop farms surveyed, the average poverty level P_0 was 0.582 (significant at 1%), average poverty level at P_1 was 0.103 and for P_2, it was 0.028 (both statistically significant at 5%).

In the crude oil polluted crop farmer households, the average poverty levels were P_0 = 0.638; P_1 = 0.087; P_2 = 0.024, significant at 1% and 10% respectively. In the non-polluted crop farmer households (Table 1), the results of the headcount (P_0) measure was 0.520 and P_1 was 0.103, both statistically significant at 1%, while the average poverty measure for P_2 was 0.027 (significant at 5%).

Poverty measures by membership of cooperative society

The poverty measures of household heads that belonged to one cooperative society or the other are shown in Table 2. The table contained results of all crop farms surveyed, crude oil polluted and non-polluted crop farms in Rivers State, Nigeria. In all crop farms surveyed, those who claimed to belong to one cooperative society or formation group or the other were 19.94% while those who do not belong to any cooperative formation were 80.06%.

The average poverty level in P_0 was 0.564 with a significance of 1%. Average P_1 poverty measure was 0.097 while that of P_2 was 0.027, both statistically significant at 1%. The results of crude oil polluted crop farms on Table 2 showed that 20.48% of them were cooperative members, 79.52% did not belong to any cooperative. Average P_0 poverty level was 0.653, P_1 was 0.092 and P_2 was 0.025, all were statistically significant at 1%. In non-polluted crop farms, only 19.53% of the interviewed respondents were members of cooperative society, while 80.47% were none members. The average poverty level of P_0 was 0.497, P_1 was 0.097 and P_2 was 0.027, all statistically significant at 1%.

Poverty measures by other working members of the household

The poverty measures of other members of the household working apart from the head of the household in all crop farms surveyed, crude oil polluted and non-polluted crop farmers households are presented on Table 3.

The results of all crop farms surveyed showed that 60.13% of the households had no other members of

Table 1. Measures of poverty by years of experience of household head in crop farming in Rivers State, Nigeria.

Years of farming experience	Percentage frequency of poverty			Head count (P_0)	Contribution to overall P_0 (%)	Poverty gap (P_1)	Contribution to overall P_1 (%)	Poverty severely (P_2)	Contribution to overall P_2 (%)
	Poor	Non-poor	Total						
All crop farms surveyed									
1 - 10 years	16.22	9.12	25.65	0.640***	7.79	0.099***	7.07	0.027**	5.92
				(0.156)	(3.50)	(0.038)	(3.76)	(0.013)	(3.91)
11 - 20 years	22.67	20.27	42.94	0.504***	37.55	0.110**	37.52	0.035**	38.73
				(0.144)	(10.59)	(0.053)	(15.10)	(0.016)	(19.70)
21 - 30 years	12.16	9.12	21.28	0.689***	33.23	0.136**	33.80	0.048*	35.68
				(0.154)	(14.23)	(0.058)	(17.71)	(0.026)	(23.58)
31 – 40 years	3.72	3.04	6.76	0.600***	11.93	0.170***	14.50	0.056***	15.05
				(0.153)	(6.63)	(0.037)	(9.24)	(0.011)	(10.72)
41 years and above	2.02	1.35	3.37	0.467***	9.32	0.073*	7.11	0.010	4.62
				(0.179)	(6.00)	(0.038)	(3.84)	(0.010)	(2.66)
Total	57.10	42.90	100	0.582***	100	0.103**	100	0.028**	100
Crude oil polluted crop farms									
1 – 10 years	18.11	4.72	22.83	0.834***	10.93	0.114***	13.57	0.027***	13.48
				(0.078)	(4.97)	(0.036)	(7.62)	(0.013)	(9.22)
11 - 20 years	23.62	18.11	41.73	0.484**	32.56	0.075*	38.73	0.023	43.35
				(0.216)	(13.21)	(0.041)	(18.69)	(0.017)	(28.10)
21 – 30 years	16.54	10.24	26.78	0.653***	35.15	0.077*	29.79	0.020	30.95
				(0.136)	(20.23)	(0.043)	(21.74)	(0.014)	(25.86)
31 - 40 years	3.94	1.57	5.51	0.800***	11.85	0.128***	13.14	0.029***	10.57
				(0.142)	(11.71)	(0.032)	(12.84)	(0.011)	(10.48)
41 years and above	2.36	0.79	3.15	0.833***	9.51	0.050***	4.77	0.004***	1.65
				(0.118)	(9.31)	(0.013)	(4.76)	(0.001)	(1.69)
Total	64.57	35.43	100	0.638***	100	0.087***	100	0.024*	100
Non-polluted crop farms									
1 - 10 years	14.79	12.43	27.22	0.652***	9.56	0.126**	8.94	0.040	8.46
				(0.179)	(5.69)	(0.063)	(5.91)	(0.028)	(6.65)
11 - 20 years	21.89	21.89	43.78	0.468**	39.04	0.108**	38.57	0.036*	43.25
				(0.190)	(16.79)	(0.056)	(20.06)	(0.20)	(26.28)
21 – 30 years	8.88	8.28	17.16	0.668***	24.38	0.149***	25.80	0.038***	24.00
				(0.256)	(13.80)	(0.033)	(15.21)	(0.007)	(15.10)
31 – 40 years	3.55	4.14	7.69	0.500***	14.58	0.118**	17.40	0.031**	17.55
				(0.153)	(7.23)	(0.043)	(8.89)	(0.013)	(9.49)
41 years and above	2.37	1.78	4.15	1.000***	12.44	0.148***	9.29	0.029**	6.80
				(0.000)	(5.62)	(0.041)	(5.00)	(0.012)	(4.34)

Table 1. Contd.

Total	51.48	48.52	100	0.520***	100	0.103***	100	0.027**	100

Source: Field survey, 2003. Asterisks indicate significance level ***1, **5 and *10%. Figure in parentheses are standard errors.

Table 2. Measures of poverty by household head membership of cooperative society in Rivers State, Nigeria.

Membership of cooperative society	Percentage frequency of poverty			Head-count (P_0)	Contribution to overall P_0 (%)	Poverty gap (P_1)	Contribution to overall P_1(%)	Poverty severely (P_2)	Contribution to overall P_2 (%)
	Poor	Non-poor	Total						
All crop farms surveyed									
Member	13.18	6.76	19.94	0.633***	12.67	0.106***	12.34	0.025***	10.27
				(0.062)	(0.02)	(0.015)	(0.024)	(0.005)	(0.026)
Non-member	43.91	36.15	80.06	0.555***	87.33	0.096***	87.66	0.027***	89.73
				(0.032)	(0.02)	(0.009)	(0.024)	(0.004)	(0.026)
Total	57.09	42.91	100	0.564***	100	0.097***	100	0.027***	100
Crude Oil polluted crop farms									
Member	14.17	6.31	20.48	0.586***	11.56	0.151***	21.20	0.066***	12.89
				(0.092)	(2.80)	(0.039)	(5.99)	(0.024)	(2.38)
Non-member	50.39	29.13	79.52	0.663***	88.44	0.083***	78.80	0.019***	87.11
				(0.048)	(2.40)	(0.011)	(5.99)	(0.004)	(2.38)
Total	64.56	35.44	100	0.653***	100	0.092***	100	0.025***	100
Non – polluted crop farms									
Member	12.43	7.10	19.53	0.700***	13.73	0.122***	9.74	0.029***	10.34
				(0.084)	(2.98)	(0.021)	(1.78)	(0.007)	(3.27)
Non-member	39.05	41.42	80.47	0.475***	86.27	0.095***	90.26	0.027***	89.66
				(0.042)	(2.98)	(0.011)	(1.78)	(0.004)	(3.27)
Total	51.48	48.52	100	0.497***	100	0.097***	100	0.027***	100

Source: Field survey, 2003. Asterisks indicates significance level ***1, **5 and *10%. Figures in parentheses are standard errors.

the household working, while only 39.87% of the households had such category of workers. The coefficient for average poverty level for P_0 was 0.573; P_1 was 0.098, while the average for P_2 was 0.027 (all statistically significant at 1% level. The results of the crude oil polluted crop farms in Table 3 showed that 62.99% of the households surveyed had no other working members, while about 37.01% had. The average coefficient value for P_0 was 0.659, that of P_1 was 0.099 and P_2 was 0.030, all statistically significant at 1% level. The non-polluted crop farms results (Table 3) indicated that about 42.01% of the interviewed respondents claimed to have other working members in their households, while 57.99% said they had none.

Table 3. Measures of poverty by other working members of the household in the study area.

Other working members of the household	Percentage frequency of poverty			Head count (P_0)	Contribution to overall P_0 (%)	Poverty gap (P_1)	Contribution to overall P_1(%)	Poverty severely (P_2)	Contribution to overall P_2 (%)
	Poor	Non-poor	Total						
All crop farms surveyed									
With working members	23.32	16.55	39.87	0.565***	42.02	0.096***	42.18	0.027***	42.19
				(0.037)	(6.06)	(0.009)	(4.85)	(0.004)	(6.52)
No working members	33.78	26.35	60.13	0.580***	57.98	0.100***	57.82	0.027***	57.81
				(0.045)	(3.81)	(0.012)	(4.85)	(0.004)	(6.52)
Total	57.10	42.90	100	0.573***	100	0.098***	100	0.027***	100
Crude oil polluted crop farms									
With working members	25.20	11.81	37.01	0.613***	38.98	0.099****	42.14	0.029***	39.65
				(0.056)	(5.31)	(0.016)	(7.82)	(0.009)	(11.39)
No working members	39.37	23.62	62.99	0.692***	61.02	0.098***	57.86	0.032***	60.35
				(0.064)	(5.31)	(0.021)	(7.82)	(0.010)	(11.39)
Total	64.57	35.43	100	0.659***	100	0.099***	100	0.030***	100
Non-polluted crop farms									
With working members	21.89	20.12	42.01	0.485***	40.32	0.089***	37.67	0.024***	36.13
				(0.049)	(5.23)	(0.012)	(6.03)	(0.004)	(7.65)
No working members	29.59	28.40	57.99	0.561***	59.68	0.115***	62.33	0.033***	63.87
				(0.061)	(5.23)	(0.017)	(6.03)	(0.007)	(7.45)
Total	51.48	48.52	100	0.528***	100	0.104***	100	0.029***	100

Source: Field survey, 2003. Asterisks indicate significance level ***1, **5 and *10%. Figures in parentheses are standard errors.

The average coefficient value of headcount poverty (P_0) was 0.528, P_1 was 0.104 and P_2 was 0.029 respectively and they were all significant at 1% level.

DISCUSSION

Poverty measures by years of farming experience

There is likelihood of reduction in poverty in the households if the heads were adequately experienced in crop farming. There could be an increase in poverty level if, the crop farms were polluted by crude oil, years of experience in crop farming notwithstanding. From the headcount (P_0) results in all crop farms surveyed on Table 1, incidence of poverty was highest among the 21 to 30 years of farm experience category, where 68.90% were poor, followed by 1 to 10 years group (64.0%), 31 to 40 years group (60.0%) and 11 to 20 years (50.4%). The intervals of years of crop farming experiences of 11 to 20 years and 21 to 30 years contributed about 70.78% of the overall incidence of poverty in P_0 ratio (both significant at 1%). In the poverty gap ratio (P_1), the interval of 31 to 40 years had the highest level of poverty where about 17.0% of the respondents in this group were very poor (or poorer), followed by 21 to 30 years group with 13.6% of the respondents being poorer than others. Again, the 11 to 20 years and 21 to 30 years groups accounted for more than 71.32% of the overall poverty in P_1 (both significant at 5%). At the P_2 (poverty severity) level, the 31 to 40 years group had the highest number of crop farmer households who were severely poor (5.6%), and followed by 21 to 30 years (4.8%).

The 11 to 20 years and 21 to 30 years groups still contributed the highest quota (74.41%) in the overall poverty measure. This showed that the crop farmers who were experienced between 11 to 40 years provided the highest number of poor farmer households.

Table 1 also indicated the results of crude oil polluted crop farms. At the head count level (P_0), the results showed that the incidence of poverty was highest among the households with 1 to 10 years of farming experience (83.4% of the members of the group were poor), followed by 41 years and above (83.3%) and 31 to 40 years (80%), all significant at 1%. The interval of 11 to 30 years again contributed the highest level of incidence of poverty (67.71%) in the overall P_0 poverty level. In the P_1 measure, the group of 31 to 40 years of farming experience had the highest level of very poor (poorer) households (12.8%) and followed by 1 to 10 years (11.4%). Those households in the categories of 11 to 30 years of farming experiences also contributed more than 68.52% of the overall poverty among those deep in poverty. Poverty severity was worse in the group of 31 to 40 years with about 2.9% of the group being severely poor and this was followed by the 1 to 10 years interval where 2.7% of the group was severely poor both significant at 1%. The category of 11 to 30 years, again contributed the highest to overall poverty in P_2 measure (74.3%). Among the crude oil polluted crop farmer households, the 31 to 40 years category had the highest level of poverty at the P_0, P_1 and P_2 level respectively, followed by 1 to 10 years group, while the households heads who had 11 to 20 and 21 to 30 years of farming experience contributed the highest to the overall poverty at the incidence, depth and severity levels.

The results of non-polluted crop farms in Table 1 showed that 51.48% of the respondents were poor, while 48.52% were not poor. In the P_0 ratio, the results showed that there was absolute poverty among the group of 41 years and above (100%). This is a surprising result, as these household heads were the most experienced in crop production. Incidence of poverty was high among 21 to 30 years group (66.8%), followed by 1 to 10 years category (65.2%), both significant at 1% respectively. About 63.42% of the overall poverty in P_0 was contributed by the interval of 11 to 30 years of experience combined. At the P_1 level, the depth of poverty was very high among the 21 to 30 years of experience (14.9%) followed by 41 years and above (14.8%), significant at 1% respectively. More than 64% of the overall poverty of the population in P_1 was contributed by households in 11 to 30 years intervals. Following the results in P_2 class, severity of poverty concentrated among households in 1 to 10 years farming experience (4.0%), followed by 21 to 30 years (3.8%) and the results were significant at 1%. About 67.25% of the overall poverty in P_2 was contributed by the households in 11 to 30 years of crop farming experience.

The results analyzed above, showed that there was higher level of incidence of poverty in the crude oil polluted crop farms than in the non-polluted crop farms and all crop farms surveyed in the state. This is evident from the average total figures of the incidence of poverty of 63.8% experienced by households in crude oil polluted crop farms as compared to 52.0 and 58.2% incidence (P_0) of poverty levels experience by households in non-polluted crop farms and all crop farms surveyed in the state respectively. The difference in the incidence of poverty (P_0) could have been caused by crude oil pollution on the crop farms (Edino et al., 2010; Efe, 2010). There existed generally poverty in the state, as the results showed. However, it was made worse by the presence of crude oil pollution on crop farms in Rivers State, Nigeria, the crop farming experience of the farmer being irrelevant. This result is similar to the results of Dercon (2006).

Poverty measures by membership of cooperative society

The poverty measures of household heads that belonged to a cooperative society were shown on Table 2. It is expected that a household head membership of one or more cooperative societies will reduce poverty in a given household, while if the head of a household does not belong to any cooperative society, there is likelihood of an increase in poverty in the household (Waeterloos and Rutherford, 2004; Thorp et al., 2005; Maertens and Swinnen, 2007).

In all crop farms surveyed in Rivers State, Nigeria, 43.91% of those who did not belong to a cooperative society were poor while only 13.18% of those who belong to cooperative societies were poor. In the P_0 measure, about 63.3% of the respondents who claimed to belong to cooperative societies were headcount poor, while about 55.5% of those who did not belong to any cooperative society were affected by incidence of poverty (both statistically significant at 1%). However, the none membership group contributed about 87.33% of the overall poverty in headcount ratio. The depth of poverty was higher in the group that claimed to belong to cooperative society (10.6%) as against 9.6% of the group of those who did not join cooperatives. In P_1 measure, 87.66% of the depth in poverty was contributed by those who did not belong to cooperative societies. At the poverty severity level (P_2) those who belonged to the cooperative societies were severely affected by poverty at 2.5% level, while those who did not belong had about 2.7% of them severely affected by poverty (all significant at 1%). However, 89.3% of the overall contributions to poverty in the P_2 group were contributed by those who did not belong to the cooperative societies. These results showed generally that poverty existed in Rivers State among the crop farmer households, but was more evident in the households that did not join cooperative societies.

In crude oil polluted crop farms, 50.39% of the none cooperative society members were poor, while in the group who joined cooperatives; it was only 14.17% of them that were poor. At the headcount (P_0) level (58.6%) of those who were cooperative members and 66.3% of none members of cooperative were affected by incidence of poverty respectively. About 88.44% of the overall poverty was contributed by the non cooperative member households. The P_1 ratio results in crude oil polluted crop farms showed that about 15% of those who were members were deep in poverty, while 8.3% in the none membership category were deep in poverty, though they contributed more than 78% of the overall poverty in P_1 measure and 87.11% in the P_2 level (all results were significant at 1%). These results also showed that poverty was high in crude oil polluted crop farmer households with the incidence of poverty concentrating more among the none members and they also contributed between 78.80 to 88.44% of the overall poverty. These results were similar to the results of Thorp et al. (2005) and Maertens and Swinnen (2009).

In non-polluted crop farms, 39.05% of the poor were none members, while 12.43% of the poor were members. In the headcount (P_0) measure, the results showed that incidence of poverty concentrated among the members (70%), while none members had 47.5% incidence of poverty. The none members contributed more than 86% of the overall poverty in P_0 level. In the P_1 group, 12.2% of the members of cooperative society were deep in poverty, while 9.5% of the non members were deep in poverty. The none membership group contributed highest in overall poverty in P_1 (90.26%). In the P_2 category, members that were severely poor were 2.9%, in the none membership category, poverty was very severe amongst 2.7% of the households (all statistically significant at 1% level). The none membership category contributed about 89.66% of the overall poverty in P_2 measure. Again results obtained in non-polluted crop farms showed that there was poverty existing in the households, despite the fact that majority of the overall poverty (86.27 to 90.26%) were contributed by the none members as earlier observed.

In comparison, it was observed that poverty existed on crop farmer households in Rivers State, Nigeria in all categories of farms. Majority of the poverty was contributed by none members of cooperative societies in the state, in most cases occurring for more than 80%. However, poverty was relatively higher amongst the none member households in crude oil polluted crop farms (66.3%) as against 47.5 and 55.5% in non-polluted and all crop farms surveyed in Rivers State, Nigeria. Also, in the crude oil polluted crop farms, the average incidence of poverty was higher (65.3%) when compared to the values of 49.7 and 56.4% in non-polluted and all crop farms surveyed respectively. These higher levels of poverty noted above, could have been caused by the negative effects of crude oil pollution on crop farms in Rivers State, Nigeria (Eweje, 2006; Edina et al., 2010; Efe, 2010). The results are different from the researches of Agudelo et al. (2003); Swinton et al. (2003), and Swinton and Quiroz (2003). These researchers found out that household poverty were not correlated with environmental degradation while this study found out that the higher poverty levels experienced by households were as a result of crude oil pollution on their environment.

Poverty measures by other working members of the household

Among crop farm families, an additional variable included is a binary variable that indicates whether or not the household head has other working members in his/her household. The household occupation ratio (ratio of employed household members to the total household members) is negatively related to the likelihood of poverty. A higher ratio reduces the likelihood of poverty. The probability of poverty is expected to increase if the household head does not have other working members in the household.

In all crop farms surveyed in Rivers State (Table 3) the results showed that 23.32% of the household with extra working members (outside the household head) were poor, while 33.78% of those household without any additional working member were poor. At the P_0 level, 56.5% of the households with additional working members experienced incidence of poverty, while a higher percentage (58.0%) of the household without other working members experienced incidence of poverty. In the P_1 level, about 9.6% of those households with extra working members were deep in poverty while 10% of those without extra working members were deep in poverty. In all crop farms surveyed, the households without additional working member contributed higher percentage of overall population poverty with 57.98% at P_0, 57.82% at P_1 and 57.81% at P_2 (all figures were statistically significant at 1%).

Table 3 indicated the probability of poverty occurrence in a household with or without other working members in crude oil polluted crop farms. The study observed that more than 64% of the respondents were poor of which 25.20% of them were household heads with other working members. There was a high level of poverty observed at the headcount (P_0) ratio where 69.2% of households without additional working members were poor, while 61.3% of the households with working members were poor. This meant that those without other working members experienced more poverty during the period of survey and contributed more to the overall poverty in the P_0 category with 61.02% of poverty as compared to 38.98% in the households with other working members. At the depth of poverty (P_1) and poverty severity (P_2) levels, the contributions to overall poverty were 57.86 and 60.35% respectively, which maintained that poverty of households without other working members was worse than poverty in households with other working members.

Table 3 further showed that 51.48% of the household heads were poor, of which 21.89% were having other working members in the households in non-polluted crop farms. However, a total of 48.52% were not poor. The P_0 value for household heads without additional working members was 56.1%, while the value of P_0 for households with extra working members was 48.5%. The P_0 (59.68%), P_1 (62.33%) and P_2 (63.87%) results showed that the households without other working members contributed more to overall population poverty as compared to the households with extra working members.

In comparison, the results of the study showed that there was poverty existing in Rivers State, Nigeria, irrespective of the category of farms studied with average incidence of poverty being 65.9% in crude oil polluted crop farms, 52.8% in non-polluted crop farms and 57.3% in all crop farms surveyed. The results also showed that there was more poverty experienced at the P_0, P_1, and P_2 levels in the households without extra working members, which contributed 57.81 to 63.87% of the overall poverty in the population than in the households with additional working members whose contributions were 36.13 and 42.19%. These results are similar to Dorward et al. (2004), Adams and Page (2005), Grupta et al. (2009) and Maertens and Swinnen (2009). The results further showed that incidence of poverty was higher in crude oil polluted crop farms with households without additional working members experiencing poverty up to 69.2% as compared to 56.1% in non-polluted crop farms and 58% in all farms surveyed. Even in the households with other working members, poverty was more severe in crude oil polluted farms (61.3%) as compared to 48.5% in non-polluted crop farms and 56.5% in the all crop farms surveyed. The reason for these differences could be the presence of crude oil pollution on crop farms in Rivers State, Nigeria. Therefore, crude oil pollution makes the crop farmer households to experience more poverty (Osuji and Nwoye, 2007; Idemudia, 2008; Orogun, 2009; UNEP Report, 2011; Platform, 2012).

CONCLUSION

This study observed that poverty existed generally in crop farmer households in Rivers State, Nigeria in all categories of crop farms and all socio-economic variables studied. The results of the poverty measures by years of experience of household head in crop farming in Rivers State, Nigeria showed that poverty was more pronounced amongst the 1 to 30 years group of farming experiences ranging from 72.98 to 80.33% as their contributions to overall poverty in the population. The results on years of crop farming experience in Rivers State also showed that there was higher level of incidence of poverty (P_0) in crude oil polluted crop farmer households with average poverty incidence of 63.8% as compared to 52% in non-polluted crop farmer households and 58.2% in all crop farms surveyed category.

Majority of poverty was contributed by none members of cooperative societies, in most cases occurring for more than 80%. Also, there was more incidence of poverty (P_0) experience in crude oil polluted crop farmer households (65.3%) than in non-polluted crop farmer households (49.7%) and in all crop farmer households surveyed (56.4%) in the state using household heads membership to cooperative societies as yardstick in Rivers State, Nigeria.

The results of this study showed that there was more poverty experienced at the P_0, P_1, and P_2 levels in the households without other working members, contributing 57.81 to 63.87% of the overall poverty in the population than in the households with additional working members whose contributions ranged from 36.13 to 42.19%. The results further showed that incidence of poverty (P_0) was higher in crude oil polluted crop farmer households (65.9%) as compared to 52.8% in non-polluted crop farmer households and 57.3% in all crop farms surveyed in Rivers State, Nigeria.

The supposed reason for the increase in the level of incidence of (P_0) in crude oil polluted crop farms could be due to the presence of crude oil pollution on crop farms in Rivers State, Nigeria. Therefore, crude oil pollution, caused by crude oil exploration, exploitation and production, in Rivers State, Nigeria increased the poverty level experienced by crop farmers (Idemudia, 2008) hence; the study confirmed that crude oil pollution impoverished the crop farmer (Onwuka, 2005; Chikere et al., 2009; Platform, 2012).

RECOMMENDATIONS

This study therefore makes the following recommendations to ameliorate the high incidence of poverty being experienced by crop farmer households in crude oil polluted areas.

(i) Crop farmer households who have suffered economic losses and therefore became poorer, due to crude oil pollution on their farmland should be financially compensated after qualified experts had evaluated and sanctified their claims (UNEP's Report, 2011) thereby alleviating them from poverty. This will enable them establish other businesses that may not easily be affected by crude oil pollution in the area which might make them escape poverty.
(ii) Secondly, there should be increase in sources of non-farm income and diversification of existing sources of income which will reduce over dependence on farmland

and hence poverty experienced in crude oil polluted crop farmer households. This could be done by job creation to increase the number of other working members of the households. It is also expected that household heads joining cooperative societies (Thorpe, 2005) to increase their sources of income (Gupta et al., 2009; Maertens and Swinnen, 2009) could help reduce the poverty experienced by crop farmer households in Rivers State, Nigeria as observed in this study.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Levels and phases of defoliation affect biomass production of pearl millet ADR 300

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The aim of this study was to assess biomass production of pearl millet as a function of levels and phases of defoliation. The experiment was carried out in a protected environment at the Fazenda União experimental farm in the municipality of Nova Xavantina, MT, Brazil, in 8 dm^3 capacity pots in soil classified as dystrophic red Latosol. The experimental design used was randomized blocks in a 5 × 3 + 1 factorial arrangement, with five phases of defoliation (three expanded leaves, six expanded leaves, flag leaf, booting, full flowering), three levels of defoliation (33, 66 and 99%), and an additional treatment without defoliation, with three replications. The pearl millet cultivar ADR 300 was used. Plant height, number of tillers, total dry biomass of the seed heads, and total dry biomass of the plants during the leaf rolling phase was assessed. It was observed that plant height at all levels and phases of defoliation was greater than the control. For number of tillers, a reduction was observed in the booting phase and full flowering phase at all levels of defoliation; and three expanded leaves and flag leaf phases for the levels of 66 and 99% defoliation. Total biomass of the panicle at all levels and phases of defoliation was less than the control. For total dry biomass, there was a statistical difference in relation to the control when the plants were subjected to 33% defoliation in the booting phase and full flowering phase, and 66 and 99% defoliation in all the phases. A fall in production of total dry biomass of the plant greater than 53% was observed with total elimination of the leaves during the flag leaf phase.

Key words: Leaf area, damage level, *Pennisetum glaucum*, no-till planting.

INTRODUCTION

Brazil stands out on the agricultural scene as a producer of soybean, common bean, corn, cotton, and dryland rice. Most of the agricultural areas of these crops are concentrated in the Cerrado (Brazilian tropical savanna) biome. Nevertheless, in Cerrado soils, such as Latosols, Neosols, Argisols, most of the time, fertility is restricted to the surface soil layer, and the loss of organic matter from this layer reduces the productive potential of these soils (Petter et al., 2013). Thus, advances in these areas are ensured with the introduction of the No-Till Planting System (NTP). This management technique has been used especially in the soybean crop.

The NTP is characterized by crop rotation and by allowing crop litter and plant residues to remain on the

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Table 1. Chemical composition of the soil dystrophic red Latosol (0-0.20 m) before setting up the experiment at the Fazenda União experimental, Nova Xavantina, MT, Brazil.

pH $CaCl_2$	Ca^{2+}	Mg^{2+}	Al^{3+}	H^{+}+Al^{3+}	SB	CEC	P	K	OM	V
	------------------ $cmol_c$ dm^{-3} ------------------						--mg dm^{-3}--		g kg^{-1}	%
5.40	1.14	0.60	0.00	2.90	1.90	4.80	42.00	65.00	6.40	39.70

H + Al: potential acidity; SB: sum of bases; CEC: cation exchange capacity at pH 7.0; OM: organic matter; V: base saturation.

soil surface, which are subsequently turned over only in the crop row for depositing seed and fertilizer (Reis et al., 2007). It is based on four basic requirements: crop rotation, maintaining plant residue on the soil, not turning the soil over, and integrated management of pests and diseases.

In the literature, there are studies on diverse species of cover crops with a view toward biomass production (Pacheco et al., 2008; Torres et al., 2008; Menezes et al., 2009; Pacheco et al., 2011). In these studies, pearl millet [*Pennisetum glaucum*] has been seen as the best crop since it exhibits high biomass production between crop seasons, as well as greater resistance to water deficit (Pacheco et al., 2013; Petter et al., 2013), and it is recommended for growing between crop seasons under low rainfall conditions.

Since pearl millet is a between-season crop for the purpose of creating biomass in this period, there is a lack of interest on the part of farmers in controlling defoliating insects, among which the following stand out: lesser cornstalk borer *(Elasmopalpus lignosellus)*, sugarcane borer *(Diatraea saccharalis)*, fall armyworm *(Spodoptera frugiperda)*, and greenbug *(Schizaphis graminum)*, which may compromise biomass production.

Attacks from defoliating insects directly lead to reduction in photosynthetic area, which may reduce biomass production and also yield. Since the production of photoassimilates arises from the photosynthesis generated by the leaves, any factor that affects leaf area may affect plant development.

Even so, chemical control of defoliating insects should be avoided since this results in environmental pollution and an increase in the final cost of production; therefore, identification of the period(s) of greater crop sensitivity to defoliation arising from the attack of insect pests will result in a decrease in the number of applications of agricultural chemicals and will consequently reduce environmental damages and production costs (Barros et al., 2002).

Studies on this theme have found that defoliation reduces plant development, which directly affects production. These effects have been observed in soybean (Barros et al., 2002; Costa et al., 2003; Zuffo et al., 2015), corn (Alvim et al., 2010), sunflower (Lima Junior et al., 2010), rice (Bertoncello et al., 2011), and sorghum (Fonseca et al., 2013). Nevertheless, there are no studies on the phases and levels of defoliation in the pearl millet crop.

Thus, the aim was to assess biomass production of pearl millet as a function of levels and phases of defoliation.

MATERIALS AND METHODS

The experiment was carried out at the Fazenda União (experimental farm) in the municipality of Nova Xavantina, MT, Brazil (14° 50' 41" latitude South, 52° 22' 49'' longitude West, with a mean altitude of 290 m) in the period from June to August 2013.

The soil used in the experiment was collected in a soybean production area from the 0-0.20 m layer. The following physical characteristics were found in soil analysis: 500, 100, and 400 g kg^{-1} of sand, silt, and clay, respectively. Chemical composition of the soil in the experimental area is shown in Table 1.

Climate in the region is Aw, according to the Köppen global climate classification, with two well-defined seasons: a dry season from May to September and a rainy season from October to April. Climate data were collected at the meteorological station of the Instituto Nacional de Meteorologia – INMET and are shown in Figure 1.

A randomized block experimental design was used in a 5 × 3 + 1 factorial arrangement, with five phases of defoliation [three expanded leaves (10 days after plant emergence - DAE), six expanded leaves (20 DAE), flag leaf (30 DAE), booting (40 DAE), full flowering (50 DAE)], three levels of defoliation [33, 66, 99%], and an additional treatment without defoliation, making for a total of 16 treatments, with three replications. Defoliation was characterized by random removal of leaves from the plant with the aid of a scissors.

The pearl millet was grown in 8 dm^3 capacity pots. Five seeds were sown per pot at a sowing depth of 1 to 2 cm and afterwards thinned, leaving only one plant. The fertilizer applied was 3 g of limestone and 10 g of the formulate NPK 02-20-20 per pot. At 30 DAE, 2.0 g of urea per pot was applied in topdressing. During the time of the experiment, the plants were irrigated daily to replenish water lost through evapotranspiration and to maintain soil field capacity.

During plant development, the following management practice was used: (i) two applications of insecticide, thiamethoxam + lambda-cyhalothrin (Platinum Neo®) at the rate of 200 mL c. p. (commercial product) ha^{-1}, applied at 20 and 45 DAE; ii) one application of fungicide pyraclostrobin + epoxiconazole (Opera®) at the rate of 500 mL c. p. ha^{-1}, applied at 40 DAE. Weeds were removed manually so as to eliminate the effect of weed competition on pearl millet. A CO_2 pressurized backpack sprayer coupled to a spray boom with four XR 110.02 spray nozzles was used for application, applying a volume of the mixture of 200 L ha^{-1}.

In the leaf rolling phase, which is characterized by grain filling and maximum accumulation of dry biomass, the following were determined: a) plant height - determined from the soil surface to the tip of the seed head with the aid of a ruler, in millimeters; b) number

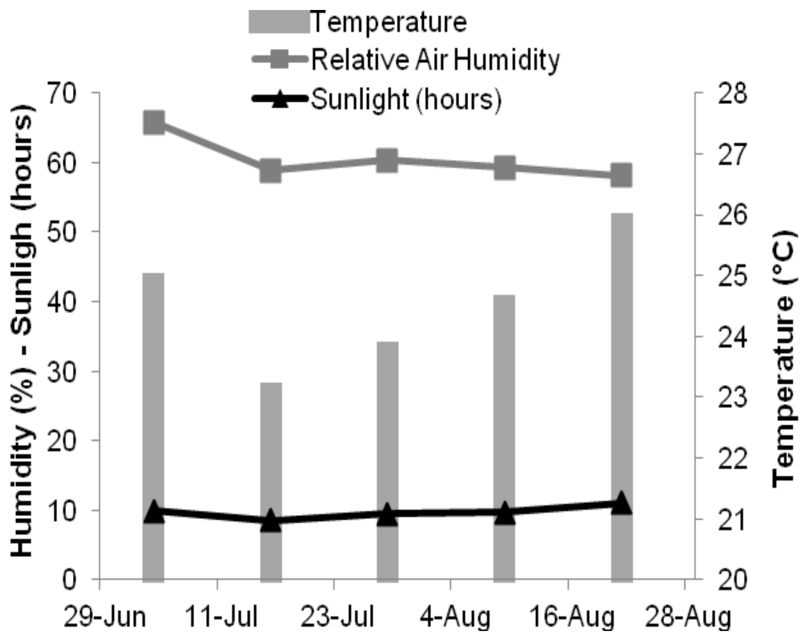

Figure 1. Mean temperature, relative air humidity, and sunlight hours over the period of the experiment (data from INMET – Nova Xavantina station, MT, Brazil).

Table 2. Summary of analysis of variance of the data related to plant height (PH), number of tillers (NT), total dry biomass of the panicle (DBPA), and total dry biomass of the plant (DBPL) obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Sources of variation	DF	Mean squares			
		PH	NT	DBPA	DBPL
		cm	unit	- - - - - - g - - - - - -	
Blocks	2	285.14	6.08	1.49	21.83
Defoliation (D)	2	1472.57**	8.86**	6.92**	4461.74**
Phase (E)	4	578.65*	7.20**	5.54**	1085.45**
D x E	8	118.98^{ns}	0.86^{ns}	0.96^{ns}	386.10**
Factorial *vs* Additional	1	1593.11**	10.51**	132.16**	2526.00**
Treatments	15	520.11**	4.26**	8.99**	1258.67**
Residues	30	192.34	0.92	0.68	64.02
Corrected Total	47				
CV (%)		8.20	17.11	14.59	9.38

** and * significant at the level of 1 and 5% probability by the F test, respectively. ^{ns} – not significant; DF – degree of freedom; CV – coefficient of variation.

of tillers - measured in a manual way in the pot; and c) total dry biomass of the panicle and total dry biomass of the plant, with the aid of a forced air circulation laboratory oven at 60°C for 72 h until obtaining constant weight, and after that the plant residues were weighed on a precision balance (0.001 g).

After collecting and tabulating the data, analysis of variance was carried out of the data obtained in all the parameters evaluated. Comparison of the defoliation treatments and the comparison of each mean value of the defoliation treatment versus the additional treatment (control) were made by the Scott-Knott test at 5% probability. The statistical program Sisvar (Ferreira, 2011) was used to carry out the analyses.

RESULTS AND DISCUSSION

The summary of analysis of variance of the data obtained is shown in Table 2. It may be observed that for plant height (PH), number of tillers (NT), total dry

Table 3. Mean values of plant height obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)			Mean value
	33	66	99	
	Plant height - PH (cm)			
Three expanded leaves	194.50*	162.00	158.66	171.72^{B}
Six expanded leaves	192.33*	184.00*	175.66*	184.00^{A}
Flag leaf	179.00*	164.00	162.33	168.44^{B}
Booting	173.00*	169.33	165.33	169.22^{B}
Full flowering	172.00*	161.33	153.16	162.16^{B}
Mean	182.16^{a}*	168.13^{b}	163.03^{b}	171.11

In the column, the mean values followed by the same uppercase letter, and, in the row, by the same lowercase letter, belong to the same group by the Scott Knott test at 5% probability. * Mean values statistically different from the mean value of the control without defoliation (147.33 cm) by the Scott Knott test at 5% probability.

Table 4. Mean values of number of tillers obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)			Mean value
	33	66	99	
	Number of tillers - NT (unit)			
Three expanded leaves	7.33	5.33*	4.66*	5.77^{B}
Six expanded leaves	8.33	6.66	6.33	7.11^{A}
Flag leaf	6.33	5.66*	5.33*	5.77^{B}
Booting	6.00*	4.66*	5.33*	5.33^{B}
Full flowering	5.00*	5.00*	4.00*	4.66^{B}
Mean	6.60^{a}*	5.46^{b}*	5.13^{b}*	5.73

In the column, the mean values followed by the same uppercase letter, and in the row, by the same lowercase letter, belong to the same group by the Scott Knott test at 5% probability. * Mean values statistically different from the mean value of the control without defoliation (7.66 cm) by the Scott Knott test at 5% probability.

biomass of the panicle (DBPA), and total dry biomass of the plant (DBPL), there was a significant effect of the phases and of the levels of defoliation applied. Significant interaction between both factors occurred for total dry biomass of the plant. With the exception of the parameter of total dry biomass of the plant, the parameters led to an isolated study of the level and phase factors of defoliation.

The mean values of the data obtained for plant height may be seen in Table 3. In general, it was observed that plant heights at all levels and phases of development were greater than the control. There was a significant effect at the lowest level of defoliation and at all levels in the defoliation phase with six expanded leaves. A greater increase in plant height (32.01 and 30.54% in relation to the control) was observed when the plants were defoliated at 33% in the initial phases of three and six expanded leaves, respectively. It is clearly shown that when defoliation is performed, the remaining leaves promote a compensatory effect in which they are able to produce photoassimilates and redistribute them in such a way that the plant develops.

Although, the defoliation levels promote greater plant height, upon analyzing the number of tillers, a different behavior was observed. Upon comparing all the defoliation treatments to the control, significant change was seen in the number of tillers for the booting phase and full flowering phase at all levels of defoliation; and three expanded leaves and flag leaf phases for the levels of 66 and 99% defoliation (Table 4). Such a response may have occurred as a result of the leaves concentrating the structures of the plants with a greater active photosynthetic rate, which may confer a greater amount of photoassimilates accumulated during the cycle (Taiz and Zeigler, 2009).

Defoliation limits the capturing of solar radiation and production of photoassimilates; thus, there is a decline in development of new tillers. Tillering is considered to be an advantageous characteristic because it is directly related to the number of stalks. For Sodré Filho et al. (2004), around 40% of the biomass accumulated in pearl millet is found in the stalk, which is formed by more

Table 5. Mean values of total dry biomass of the panicles obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)			Mean value
	33	66	99	
	Total dry biomass of the panicles - DBPA (g)			
Three expanded leaves	5.84*	5.23*	4.52*	5.20[B]
Six expanded leaves	6.61*	6.72*	5.90*	6.41[A]
Flag leaf	8.13*	5.62*	6.08*	6.61[A]
Booting	5.89*	5.52*	5.24*	5.55[B]
Full flowering	5.66*	5.04*	3.63*	4.78[B]
Mean	6.42[a]*	5.63[b]*	5.07[b]*	5.71

In the column, the mean values followed by the same uppercase letter, and in the row, by the same lowercase letter, belong to the same group by the Scott Knott test at 5% probability. * Mean values statistically different from the mean value of the control without defoliation (11.40 g) by the Scott Knott test at 5% probability.

Table 6. Mean values of total dry biomass of the plant obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)			Mean value
	33	66	99	
	Total dry biomass of the plant - DBPL (g)			
Three expanded leaves	108.00[Aa]	97.45[Aa]*	81.45[Ab]*	95.63
Six expanded leaves	119.42[Aa]	93.13[Ab]*	84.98[Ab]*	99.18
Flag leaf	121.34[Aa]	69.33[Bb]*	53.87[Bc]*	81.51
Booting	94.27Ba*	79.69[Bb]*	65.41[Bc]*	79.79
Full flowering	79.67Ca*	73.92[Ba]*	66.79[Ba]*	73.46
Mean	104.54	82.70*	70.50*	85.91

In the column, the mean values followed by the same uppercase letter, and in the row, by the same lowercase letter, belong to the same group by the Scott Knott test at 5% probability. * Mean values statistically different from the mean value of the control without defoliation (115.88 g) by the Scott Knott test at 5% probability.

lignified tissues and a greater C/N ratio compared to the other structures of the plant. That way, the greater the number of tillers, the slower the decomposition rate of the straw, resulting in longevity of the residues in establishing the NTP. In addition, the tillers may act as suppliers of photoassimilates in a situation of deficiency of the source, brought about by defoliation of the main stalk, as reported by Pasuquin et al. (2008) in irrigated rice and Sangoi et al. (2012) in corn.

In general, it was observed that there was a significant effect for total dry biomass of the panicle at all levels and phases of defoliation, and the mean values were less than those obtained in the control (Table 5). Total dry biomass of the panicle is directly related to production of the pearl millet crop; thus, any level and phase of defoliation affects pearl millet production. Reduction in pearl millet yield (hybrid GHB-30 and MH-179) as a function of the level of defoliation was seen by Josshi et al. (2003). The authors report that removal of a single leaf at the upper part of the stem significantly changed grain production.

Although, pearl millet yield was not assessed in the present study (because of the destruction of the plants for data collection), it may be inferred that as a result of the effects of defoliation in any phenological phase and based on the results of research (Josshi et al., 2003; Fonseca et al., 2014) that deals with the correlation of such characteristics with productive capacity, defoliation results in a decline in pearl millet yield.

For total dry biomass, when the plants were subjected to 33% defoliation in the booting phase and full flowering phase, and 66 and 99% defoliation in all the phases, there was statistical difference in relation to the control (Table 6). These results are partially the same as those obtained by Fonseca et al. (2014); upon studying levels of artificial defoliation in millet, they concluded that only defoliation of 100% in the ED1 (third visible sheet) phase was less than the other levels of defoliation.

The results may be related to a compensatory effect of the remaining leaves; however, the quantity of the photoassimilates is limited, especially in all the reproductive phases and at the defoliation levels of 66

Table 7. Percentage variation of total dry biomass of the plant in relation to the control without defoliation in pearl millet ADR 300, subjected to defoliation levels of 33, 66, and 99% in five phases of defoliation, grown in a greenhouse. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)		
	33	66	99
	Total dry biomass of the plant - DBPL (g)		
Three expanded leaves	- 6.80	- 15.90*	- 29.71*
Six expanded leaves	+ 3.05	- 19.63*	- 26.66*
Flag leaf	+ 4.71	- 40.17*	- 53.51*
Booting	- 18.64*	- 31.23*	- 43.55*
Full flowering	- 31.24*	- 36.20*	- 42.36*

* Mean values statistically different from the mean value of the control without defoliation according to the mean values shown in Table 6.

and 99%.

Defoliations carried out in all the reproductive phases and at the defoliation levels of 66 and 99% led to reduction in grain production, as seen in the data on percentage variation in total dry biomass of the plant, and of the phases and levels of the defoliation treatments in relation to the control (Table 7).

In general, a greater reduction in total dry biomass of the plant, around 53.51% in relation to the control, was seen when the plants were in the flag leaf phase and were totally subjected to defoliation, underscoring the lower biomass production because this treatment reduces the number of tillers and the total dry biomass of the panicle (Table 4 and 5, respectively). Dry biomass of the plant is correlated to the production of photoassimilates during photosynthesis. Therefore, photosynthetic efficiency in transformation of solar radiation intercepted and transformed into dry biomass (Casaroli et al., 2007) is highly dependent on leaf area (Alcântara Neto et al., 2011). Thus, damages brought about in leaves impede photosynthetic activity (Mondo et al., 2009).

Therefore, defoliation at any level and phase favors plant height. In contrast, it limits the number of tillers and total dry biomass of the plants in all the reproductive phases and at 66 and 99% defoliation levels. However, for the parameter that is directly related to the total dry biomass of the panicle, all the levels and phases of defoliation affected biomass production of pearl millet ADR 300.

According to the results, it is possible to see that small levels of defoliation in the initial phases of plant development of pearl millet do not reduce the total biomass production of the plant, probably because there is an increase in photosynthetic yield brought about by greater penetration of light into the lower layers of the plant. Therefore, there is no need for control in this condition. However, in relation to grain yield, further studies should be undertaken so as to clarify if the trends of decline in the production components found in the present study correlate with plants sown under field conditions.

In light of the results obtained, the different levels and phases of defoliation have a significant effect on all the parameters studied. The total dry biomass of the panicle is reduced when subjected to any level and phase of defoliation. The greatest reduction in production of total dry biomass is observed from the total elimination of leaves in the flag leaf phase.

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Conflict of Interest

The author(s) have not declared any conflict of interests.

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Seasonal diet preference of cattle, sheep and goats grazing on the communal grazing rangeland in the Central District of Botswana

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Diet composition, forage preference and diet overlap among of goats, sheep and cattle grazing on communal rangeland in the Central District of Botswana were evaluated to determine the potential for forage competition to provide better ideas for managing these rangelands. Diets and forage preference were determined through microhistological faecal analysis. Animal faeces and reference plant material of the study area were collected, ground to fine particles and prepared into slides of which histological features of each animal species were studied under the microscope. Features on the faecal sample slides were matched with those in the reference plant material. Estimates of forage biomass and quality were estimated along transects and species composition was determined using a wheel-point apparatus. Season was a major factor affecting herbage biomass and quality. Forage quality decreased from wet to dry season with greater decreases in grass than browse. The content of nitrogen was higher in browse than in herbage in both seasons, and the seasonal decline in browse was less than in herbage. Cattle and sheep diets constituted mostly grasses, but cattle do browse as well during the dry periods. Goats selectively concentrate on browse all the year-long and were more diverse in their diet composition than either cattle or sheep, giving the former better chances of standing harsh conditions. Preferred plant species were not the necessarily the most common on the range. Therefore, monitoring productivity and use of key forage species, particularly of grasses, should complement management objectives.Diets overlaps were generally high during dry seasons, reflected seasonal influence as animals shift diets focus, when the potentials of forage selections are restricted to limited species diversity and availability. The results suggest potential for forage competition between cattle and sheep is highest during dry seasons for grasses.

Key words: Browse, forage availability, species diversity, diet overlap, forage species selection, forage species preference.

INTRODUCTION

Research on the pattern of diet selection requires an understanding of the forage and nutritional needs of

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range animals and competitive interactions among them. Diet selection in terms of both quantity and quality is primarily a function of the types and amount of feed on offer (Pieper, 1978). Selective grazing, due to differences in relative plant palatability, is a problem confronting people concerned with the practices of correct range utilization. Two forms of selective grazing, namely species selective grazing and area selective grazing were identified (Bailey, 1995; Soder et al., 2009; Masahiko et al., 2008). The causes for differences in palatability among both grasses and other life forms are as yet not clearly understood in spite of the fact that numerous attempts had been made in the past to relate preference differences to a number of factors such as forage quality (Bailey, 1995; Van Dyne and Heady, 1965; O'Reagain and Mentis, 1989; Soder et al., 2009), frequency of grazing and forage available in the range (Gammon and Roberts, 1978; Darlene et al., 2005; Kilonzo et al., 2005).

The measurement of animal diet preferences presents numerous problems that, as yet, have not been entirely overcome. Therefore no standard method has been devised by which animal preference can be successfully measured under a variety of conditions has been devised. The faecal technique is increasingly advocated to avoid the disadvantages of other methods for developing diet of free- ranging ruminants (Sparks and Malcheck, 1968; Smith and Shandruk, 1979; Kilonzo et al., 2005; Soder et al. 2009). This method examines and depends on the identification of indigestible cutinised fragments of leaves persisting in the faeces (Storr, 1961; Sparks and Malcheck, 1968; Liversidge, 1970; Scotcher, 1979; Holechek and Gross, 1982; Kilonzo et al., 2005; Soder et al., 2009). However, the epidermal tissues of forbs were not as easily found in cattle and sheep faeces (Free et al., 1970). Also during the growing season the faecal analysis method tend to under-estimate the forbs and over-estimate the grasses (Vavra et al., 1978) in the diet when compared to fistula technique. In winter, however, the two methods were found to be comparable. Most scientists however, agree that differential digestion of plant species has little or no influence on the proportion of identifiable plant fragments (Free et al. 1970; Anthony and Smith 1974; Dearden et al., 1975; Alipayo et al., 1992; Kilonzo et al., 2005; Soder et al., 2009). Diet composition data alone are not sufficient to explaining the reason for observed diet differences between animal species, or switching of diet through the seasons. A knowledge of the reason why herbivores select the species that they eat is necessary for an understanding of the forage needs of range animals and the underlying basis of composition interaction among them (Hanley, 1982). Information on herbage availability and quality is therefore, also essential. Forage availability is necessary for determining stocking rates; determining changes in range condition and determining the responses to many other treatments (Pieper, 1978). The most widely used methods for estimating herbage availability include: a) clipping method (Mueller-Dombis and Ellenberg, 1974), b) indirect method (Cook and Stubbendieck, 1986; Jordaan et al., 1991; Pieper, 1978), c) weight estimate methods (Tadmor et al., 1975; Ahmed and Bonham, 1982; Pechanec and Pickford, 1937) and the content of alkane in the herbage Lou et al. (2004).

Variations in nutrient content occur between, and within, plant species and herbivores select their food to obtain a nutritionally balanced diet (Owen - Smith and Novellie, 1982; Hardy and Mentis, 1986; O'Reagain and Mentis, 1989; Hendricks et al., 2002; Kilonzo et al., 2005; Villalba and Provenza, 2009). Some grass species (e.g. *Panicum maximum*) are characterized by high levels of a particular element (e.g. nitrogen) and no single species can accumulate high levels of all nutrients (Pratchatt et al., 1977; Georgiadis and McNaughton, 1990; Villalba and Provenza, 2009). The variation in individual mineral concentrations, found among plant species may explain the observation that herbivores tend to diversify their diets (Bouttom et al., 1988). However, attempts to predict dietary selection on these bases in sheep (Westoby, 1974), kudu (Owen - Smith and Novellie, 1982), goats and impala (Cooper and Owen – Smith, 1985) have been unsuccessful. The latter proponents demonstrated that plant secondary metabolites (tannins) are important determinants of dietary selection among browsers.

Information on the diet preferences of large free roaming herbivores is an important tool in resource management. Such knowledge can be used in the assessment of nutrient intake of animals and evaluation of forage competition or complementary between herbivores (Holechek and Gross, 1982; McInnis et al., 1983; Hendricks et al., 2002; Kilonzo et al., 2005; Lou et al., 2004; Soder et al., 2009). This research was aimed at evaluating goats, sheep and cattle diet composition, diet overlap, and forage preference on communal grazing rangeland in Central District of Botswana to understand potential for forage competition to provide better ideas for managing these rangelands.

MATERIALS AND METHODS

Description of study area

The study was located at Makhi communal grazing area in the Central District of Botswana (approximately 26.10' degrees South and 23.40' degrees East at an elevation of 1200 m). The area is broadly described as a rolling flat country with flat dunes, wide plain depressions and pans (Weare and Yalala, 1971). The soils are classified as Ferralic arenosols (FAO, 1990). These are described as deep to very deep, well to somewhat excessively drained. The texture is fine sand to loamy fine sand and run–off is non – existent.

The region consists of sandveld vegetation type (Weare and Yalala, 1971) of the Northern Kalahari tree and bush savanna. The main tree species are *Terminalia sericea*, *Acacia fleckii, A. luederitzii,* and *Ochna pulcra*. Low growing shrubs, between taller trees, which often contribute significantly to canopy cover, include *Grewia flava, G. retirnevis, Bauhinia petersiana, Dichrostachy's cinerea Mudulea sericea* and *Searsia tenuinervis*. The grass component has a low basal cover and consists mainly of *Stipagrostis uniplumis, Eragrostis lehmanniana, Schmidtia pappophoroides, Anthephora pubescens* (perennials) and *Urochloa trichorpus, Aristida congesta, A. graciliflora* and *Megaloprotachne albescense* (annuals). Various families of forbs are also found. The mean monthly maximum temperatures range from 32 degrees centigrade in December and January to 23 degrees centigrade in June to July. The corresponding minima are 18 and 4°C, respectively. Rainfall is erratic in total and distribution, with an annual long – term mean of 451 mm.

Botanical composition of the diet of livestock was determined by analysis of faecal material using the microhistological technique as described by Sparks and Malechek (1968) and Dearden (1975) and further developed by Holechek et al. (1982). Freshly dropped dung samples were collected at three different water points (boreholes) in the case of cattle, and from rectal samples in the case of sheep and goats. These animals were grazed around each water point in common grazing range of the communal land. One or two pellets from each individual goat or sheep and a small grab sample from each mound of cattle dung were taken. At least fifteen sub - samples were collected from each animal species at a time. Sub - samples of each animal species were composited into a single sample and about 70 g was kept for the final sample. Samples were collected over seven days within each season throughout the year. Samples for cattle were preserved immediately by adding an equal amount of coarse sodium chloride (Hansen et al., 1978) and air dried.

Plant materials that included only leaves of woody species, stem and leaves for herbaceous plants in the study area were collected for use as microhistological reference slides. Slides for each faecal sample or plant reference material were prepared following the procedure described by Holechek et al. (1982). The prepared slides were then placed in a rack and dried at 60°C for 48 h and stored. These were later studied under the microscope and drawings were prepared, showing the histological features of each plant species. Five slides per faecal sample were prepared for each animal species (cattle, sheep and goats) and two slides for each plant species for the reference plant material.

A microscope using 100X magnification was used to identify plant species based on the epidermal cell characteristics. At each location (field) on the slide, plant species present were recorded. Twenty fields were read from each of the five faecal slides, resulting into a total of 100 fields per animal species sample per season. The characteristics on diet sample slides were matched with those in the reference plant material. The percentage frequency of each identified plant species was converted to density of particles per microscope field (Dearden et al., 1975; Sparks and Malechek, 1968). The relative density of fragments was then obtained from the frequency figures. Botanical composition results from microhistology were used to simulate the diet for the period for each animal species.

Forage samples (biomass and quality) were collected at the same period as the faecal samples collection to simulate the animals' diets. Available biomass was estimated using double sampling method (weight estimate method). Samples were taken at five points along the transect radiating from water point. These points were located at 100, 500, 1500, 2500 and 4000 m from the water point. These points were replicated three times at each water point. A 50 m x 50 m permanent plot at each sample point was demarcated in which herbaceous plants were measured. Within each such plot, 20 quadrates of 0.5 m^2 were randomly located to estimate herbage biomass. The first four quadrates were visually estimated and the fifth quadrate was clipped so that the visually estimated mass could be adjusted by a regression technique. The clipped samples were bagged by species and fresh mass taken and again, re-weighed after oven dry. Sampling was repeated each season over one year. Forage samples for nutrient analysis were taken at the same location were biomass estimates occurred.

Herbaceous plant species composition in the range was determined using a wheel-point apparatus were 200 points were recorded within the 50 m x 50 m permanent plot.

Data analysis

Average percent frequency of occurrence of forage species was computed by dividing number of fields in which the species occurred in 125 and then multiply by 100. For examples, if number of fields in a species occurred in 25 out of 125 fields, the frequency of that species was:

$$F = (X/Y)\ 100 = (25/125)100 = 20\%$$

Where X= # of fields in which the plant species occurred and Y = the total # of fields in 5 slides.

The density (D) of discerned fragment was then estimated from the frequency by the formula:

$$D = 1n\ (1\text{-}F/100).$$

Where 1n = natural logarithm and F = Frequency (%).

For a given frequency, a mean density of identified fragments of forage species per microscopic field was converted to a relative percent density (RD) by the formula:

$$RD_i = D^i/\sum^n{}_{J=1} D_j)\ 100$$

Where Di = the density of discerned fragments of forage species in the diet and $\sum D_j$ = the sum of the densities of discerned fragments of all forage species in the diet.

Plant species diversity was calculated to indicate the diet breadth, on the basis of Shannon-Wiener Function (Krebs 1989) formula:

$$H' = - \sum {}^n{}_{1=1}\ (p_i)(\log_e P_i)$$

Where p_i = the proportion (%) of total sample belonging to the i^{th} species in the diet and n = total number of resource states.

Plant species diversity index indicates variety and evenness of components in the diet. The index increases with an increasing number of species in the diet. High species diversity indices indicate that the animals do not rely on a few plant species for most of their diet, but feed on a broad spectrum. Animal species characterized by high species diversities are potentially better able to adapt their diet changes in plant composition (Wolda, 1981). H' was selected because it is independent of sample size. However, Wolda (1981) indicated that it was sensitive to changes of rare species in the community.

Food habit studies of more than one animal species usually compare diet overlaps between any combinations of two diets. Dung analyses for botanical composition can be used to estimate the appropriate amount of diet overlap between different animal species. Overlap between diets was calculated using Morisita's similarity index (Morisita, 1959).

$$C_\lambda = (2 \sum n_{ij}\ n) / [(\lambda_1 + \lambda_2)\ N_j\ N_k]$$

Where C_λ = Morisita's index of diversity of similarity between samples j and k (eg. between cattle and sheep), n_{ij} n_{ik} = no. of individual of species i in sample j and sample k, $N_k = \sum n_{ik}$ = total no. of species in sample k (e.g. cattle), $N_j = \sum n_{ij}$ = total no. of species in sample j (e.g. sheep), $\lambda_1 = \sum^n [n_{ij\ (ij}\ (n_{ij} - 1) / N_j\ (N_j - 1)]$; $\lambda_2 = \sum^n [n_{ik\ (ij}\ (n_{ik} - 1) / N_k\ (N_k - 1)]$.

A similarity index represents the percentage of the diet that is identical, or the percentage of the diet that is shared by two animal

Table 1. Mean biomass availability (gm^2) of individual plant species and group in each season over two years in the free range grazing area.

Plant species	Summer	Autumn	Winter	Spring	Mean
Grasses					
D. eri	29.47^{bc}	57.6^{a}	37.12^{b}	30.57^{bc}	38.74
E. leh	46.38^{ab}	58.27^{a}	49.63^{a}	32.09^{bc}	42.34
E. rig	36.32^{b}	58.3^{a}	57.78^{a}	45.06^{ab}	47.74
S. uni	68.41^{a}	87.77^{a}	67.28^{a}	49.84^{a}	68.34
S. pap	48.96^{ab}	67.4^{a}	51.83^{a}	27.18^{bc}	48.10
Misc grass	39.52^{b}	51.02^{a}	44.86^{ab}	43.39^{ab}	41.54
M. alb/U. tri	28.65^{b}	39.22^{b}	23.59^{bc}	0^{d}	20.24
D.aeg/E. afr	42.72^{b}	31.83^{b}	9.0^{d}	0^{d}	21.02
C.bie/I. dal	25.07^{b}	19.83^{c}	3.78^{d}	0^{d}	12.20
A. thu/T.ter	30.95^{b}	16.49^{c}	3.1^{d}	0^{d}	9.36
Misc forbs	21.79^{c}	25.15^{bc}	14.88^{c}	11.65^{cd}	15.84
Total	**418.24**	**512.85**	**364**	**239.76**	

Values between the seasons followed by the same superscript are not significantly different (>0.05).

species. Morisita's index was preferred over the other indices because it is independent of sample size and species diversity (Wolda, 1981) and it shows potential for forage competition between animal species.

Relative preference indices (RPI's) for different plant species by different animals were determined using Krueger's (1972) formula:

RPI = % frequency in the diet composition / % frequency on the range composition.

Following calculations of RD's and C_λ, the main effects of seasons and animals were determined using GLM procedure SAS/STAT (2008). Where significant differences occurred, scheffe's test was used to separate the means.

RESULTS

Seasonal forage availability

Herbage available on individual plant species observed during study period is illustrated in Table 1. Comparison of different seasons revealed differences in the total available biomass of all species for each season. Significantly (P<0.05) low biomass was evident during spring and high (P<0.05) biomass peaked in autumn. The available biomass of annual grasses were very low (P<0.05) during the winter following the dry weather which resulted in their disappearance during the dry season (winter and spring). Their biomass diminished starting from autumn due to the physiological nature where leaf senescence occurred followed by death of the plant. Miscellaneous grasses and forbs were somehow uniformly distributed between the seasons.

Grasses: *D.aeg = Dactylotium aegyptium, D. eri = Digitaria eriantha, E. leh = Eragrostis lehmanniana, E. rig = Eragrostis rigidior, E. afr = Eleusine Africana, M. alb = Megaloprotachne albescens, S. pap = Schmidtia papophoroides, S. uni = Stipagrostis uniplumis, U. tri = Urochloa trichopus.*

Miscellaneous grasses: *A. con = Aristida congesta, A. gra = Aristida graciliflora,E. pal = Eragrostis pallens, P, pat = Perotts patens, P. squ = Pogonarthra squarrosa, M rep = Melinis repens.*

Forbs*: A. thu = Amaranthus thumbergii, C. bie = Cassia biescensis, I. dal = Idingofera daleoides, T.ter = Tribolus terrestris.*

Most of the available biomass was contributed by perennial grasses such as *S. uniplumis, E. rigidior, E. lehmanniana, D. eriantha* and *S. pappophoroides*. The mean biomass of forbs was 11% of total grass production. However, in summer, forbs increased to about 23% production of grasses component. Dry matter content was influenced primarily by stage of growth.

Crude protein, phosphorus and fibre of individual plant species were determined to indicate whether herbivores were exposed to a steady nutrition supply in the forage across the seasons. Seasonal variation in crude protein, phosphorus and fibre of individual plant species found in the communal grazing area is illustrated in Table 2. Nutrient content in forage species varied between species and seasons (stage of maturity). Significantly (P<0.05) higher levels of crude protein, phosphorus and lower fibre content occurred in summer for all plant species and the opposite was observed in winter. Almost more than 7% crude protein was generally present in the herbage during the growing seasons, but as low as 4% during the dormant season. Annual grasses and forbs had high level of protein during the growing period but foliage of forbs got shattered off during dry period. Their crude protein and phosphorus content declined after

Table 2. Seasonal concentration in crude protein (%). phosphorus (ppm) and fibre (%) of plant species occurring in forage.

	Season											
	Summer			Autumn			Winter			Spring		
Grasses	**Protein**	**Phos**	**Fibre**	**Protein**	**Phos**	**Fibre**	**Protein**	**Phos**	**Fibre**	**Protein**	**Phos**	**Fibre**
D. eri	7.73	0.063	34.11	4.39	0.036	35.71	4.06	0.036	35.86	4.61	0.047	35.80
E. leh	6.04	0.052	34.82	4.05	0.040	34.73	3.83	0.037	36.46	4.55	0.048	36.85
E. rig	5.67	0.057	32.98	4.06	0.043	33.36	4.12	0.044	33.02	4.02	0.049	35.65
S. pap	4.98	0.073	36.21	3.72	0.041	38.26	3.55	0.035	38.71	4.27	0.044	37.30
S. uni	5.66	0.061	37.02	3.98	0.043	38.90	3.17	0.034	38.72	4.49	0.047	41.17
P. max	8.03	0.081	34.00	6.80	0.055	37.06	5.21	0.071	34.92	5.59	0.076	34.34
U. tri	9.13	0.110	30.85	5.38	0.048	32.46	5.42	0.049	35.28	4.89	0.052	35.55
M. alb	7.81	0.072	25.55	3.58	0.040	32.89	3.86	0.043	31.49	3.32	0.041	32.55
E.afr	13.67	0.209	30.21	6.07	0.068	33.41	-	-	-	-	-	-
D.aeg	15.16	0.225	29.89	9.34	0.087	30.23	-	-	-	-	-	-
Aristida spp	4.67	0.062	40.94	3.24	0.042	40.31	3.31	0.039	43.03	2.86	0.022	42.36
Forbs												
A. thu	11.69	0.289	21.70	11.2	0.217	25.0	-	-	-	-	-	-
C. bei	13.71	0.192	23.09	8.61	0.195	29.01	-	-	-	-	-	-
I. dal	16.41	0.095	23.81	6.92	0.044	30.10	-	-	-	-	-	-
T.ter	13.11	0.283	25.60	11.77	0.213	26.70	-	-	-	-	-	-
Mean	**9.56**	**0.123**	**30.75**	**6.22**	**0.082**	**33.19**	**4.06**	**0.049**	**36.39**	**4.29**	**0.053**	**36.84**
Std Dev	**±4.02**	**± 0.01**	**± 0.42**	**± 0.90**	**± 0**	**± 5.37**	**± 0.01**	**± 0.01**	**± .02**	**± 0.16**	**± 0.01**	**± 0 .78**
Woody Plants												
A. fleckii	22.82	0.182	21.7	12.56	0.130	22.32	12.83	0.082	25.97	17.80	0.110	19.56
A. gerrardii	18.15	0.120	20.90	17.04	0.098	23.26	13.56	0.074	25.44	-	-	-
B. albitrunca	18.15	0.181	19.3	18.44	0.132	22.94	14.87	0.093	22.81	17.20	0.165	21.42
B. pertersiana	21.72	0.170	22.5	16.63	0.126	26.33	10.71	0.112	28.38	18.31	0.162	19.21
C. gratissmus	17.74	0.174	20.5	13.77	0.143	24.52	9.62	0.095	28.92	-	-	-
D. cinerea	19.44	0.140	20.3	14.72	0.128	25.31	10.30	0.114	27.62	-	-	-
G. flava	15.70	0.181	15.2	14.57	0.136	28.41	9.51	0.097	29.28	16.8	0.163	21.47
O. pulcra	11.96	0.113	29.3	11.65	0.098	29.97	9.11	0.067	30.81	15.40	0.185	19.55
M. sericea	17.18	0.144	28.2	16.14	0.122	28.95	-	-	-	-	-	-
T. ericea	14.13	0.108	15.7	15.64	0.079	24.97	15.60	0.039	29.11	16.30	0.133	16.83
Z. mucronata	13.22	0.123	23.5	14.81	0.076	23.75	-	-	-	-	-	-
Mean	**17.29**	**0.148**	**21.6**	**15.08**	**0.110**	**25.52**	**11.79**	**0.07**	**27.59**	**16.97**	**0.150**	**19.67**
Std Dev	**± .54**	**± 0.01**	**± 0.32**	**± 0.70**	**± 0**	**± 4.33**	**± 0.01**	**± 0.01**	**± 0.22**	**±0 .01**	**± 0.01**	**± 0.02**

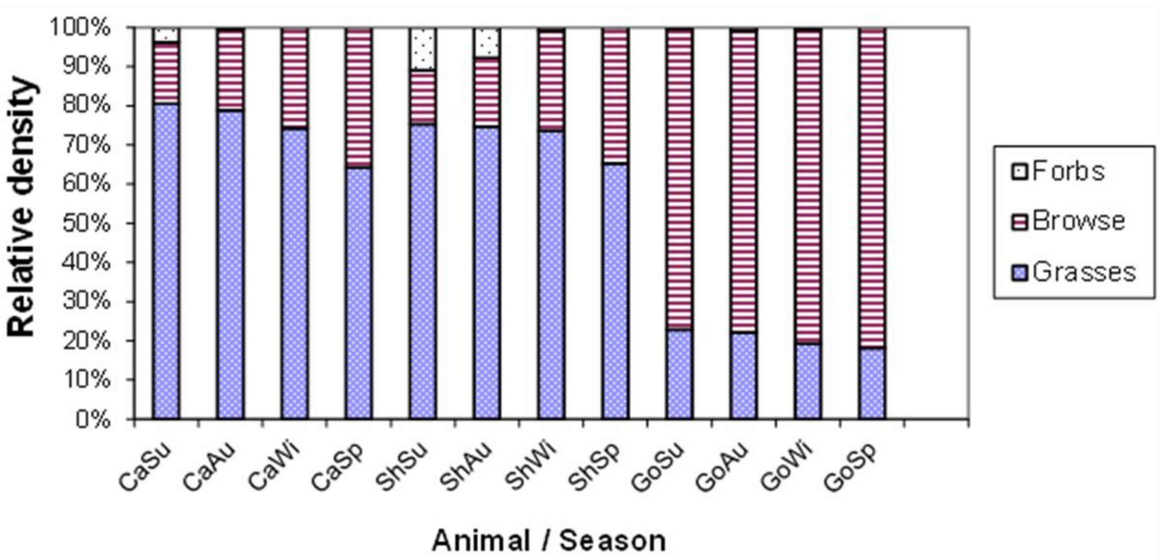

Figure 1. Average seasonal plant species class distribution between diets of cattle, sheep and goats in free ranging conditions. Key to animal / season: Ca = cattle, Sh = sheep, Go = goats, Su = summer, Au = autumn, Wi = winter and Sp = spring.

autumn to its minimum in winter.

Phosphorus content was more than two times as great in summer season as in winter. Grasses of *Aristida* spp had a very low crude protein or phosphorus content and the highest fibre content of all annual grass species during all seasons. Amongst the perennial grasses, the crude protein and phosphorus content of *D. eriantha* and *P. maximum* peaked to over 7 and 0.06%, respectively during summer and the fibre was as low as 34% (Table 2). Of the perennial grasses, S*. uniplumis* had the highest fibre content in all seasons. *Cassia biensis* and *I. daleoides*, representing the perennial forb component, were very high in both crude protein and phosphorus and low in fibre content but that their foliage shattered at the end of the autumn season due to leaf senescence and finally death of the above ground stems. The browse eaten by livestock across the seasons was relatively high in crude protein (Table 2). Crude protein and phosphorus content were at their peak in summer period, and dropped to their minimum in winter but were still above 7%, a minimum crude protein required to maintain the livestock. Phosphorus level is generally low, ranging from 0.03% in winter to 0.18% in summer for certain species.

Diet composition of cattle

Seasonal diet compositions of cattle, sheep and goats are illustrated in Figure 1. A total of 25 plant species were found in the diet of cattle of which included 75% grass, 23% browse and 2% forbs (Figure 1). Seasonally, cattle diets were dominated by grass species. Nine grass species >1% relative density occurred in the diet of cattle throughout the year and eight browse species occurred in the dung samples during the wet and dry seasons. *D. cinerea* was observed only during the summer period. Forbs were insignificantly found in the dung. The dominant grasses occurring in the diet of cattle included *D. eriantha, U. trichopus, S. pappophoroides, E. lehmanniana, M. albescens, E. rigidior* and *S. uniplumis* and woody species included *G. flava. M. sericea, C. gratissmus, B. petersiana, B. albitrunca* and *A. gerrardii* (Table 3).

Diet composition of sheep

Diet of sheep consisted of twenty one plant species; of which 74% were grasses, 21% woody species and 5% forbs (Figure 1). The dominant grass species included *D. eriantha, S. pappophoroides, M. albescens, U.trichopus, E. lehmaniana* and major woody species were contributed by *G. flava, M. sericea, C. gratissimus* (Table 4). Higher amount of grass and forbs were found in the diet of sheep during the summer period than in spring. The relative densities of browse in sheep diet were low during wet seasons and higher during dry seasons. Relative density of forbs was low (5%) but higher than that found in cattle.

Diet composition of goats

The diet of goat was composed of 78% woody species, 20% grasses and 2% forbs (Figure 1). In summer, the diet was 72% browse and this increased to 82% in

Table 3. Average relative densities (%; mean ± SE) of plant species in seasonal diets of cattle in free range grazing.

Plant species	Summer	Autumn	Winter	Spring	Mean
Grasses					
A. congesta	0.3±0.2	2 ±0.1	0	0.1 ±0.1	0.15
A. graciliflora	0.3 ±0.1	0.1 ±0.1	0.3 ±0.1	0.4 ±02	0.28
D. aegyptium	0.3 ±0.3	0.4 ±0.1	0	0	0.18
D. eriantha	9.9 ±1.2	15.1 ±0.6	14.4 ±1.2	10.7 ±0.6	12.53
E. lehmanniana	9.3 ±0.4	10.2 ±1.2	9.9 ±0.7	8.7 ±0.7	9.53
E. pallens	0.8 ±0.1	0.3 ±0.1	0.2 ±0.1	0.2 ±0.1	0.38
E. rigidior	7.4 ±1.1	8.3 ±0.8	9.4 ±0.5	13.8 ±1.2	9.73
E. africana	1.9 ±0.1	0.7 ±0.1	0	0	0.56
M. albescens	12.7 ±1.3	11.0 +1.1	8.7 ±0.9	3.9 ±0.9	9.1
P. squarrosa	0.4 ±0.1	0	0	0	0.10
M. repens	0.9 ±0.1	0.4 ±0.1	0	0	0.31
S. uniplumis	7.8 ±0.5	9.3 ±1.4	10.8 ±0.6	13.3 ±1.8	10.3
S.pappophoroides	10.4 ±1.3	12.2 ±1.6	11.7 ±0.9	9.8 ±0.9	11.0
U. trichopus	13.9 ±1.2	10.7 ±0.9	6.3 ±0.7	3.6 ±0.7	8.6
Forbs					
C. beiscensis	1.3 ±0.1	0.5 ±0.1	0	0	0.45
S. cordifolia	0.2 ±0.1	0	0	0	0.05
T. terrestris	2.3 ±0.2	05 ±0.2	0	0	0.7
Woody plants					
B. albitrunca	2.6 ±0.4	3.1 ±0.2	4.3 ±0.4	6.1 ±0.2	4.0
B. petersiana	2.9 ±0.1	2.3 ±0.3	2.9 ±0.3	3.5 ±0.1	2.90
C. gratissimus	3.4 ±0.4	4.7 ±1.2	5.9 ±0.8	7.6 ±0.5	5.40
D. cinerea	0.4 ±0.1	0	0	0	0.10
G. flava	4.4 ±0.3	4.9 ±0.6	6.2 ±0.7	8.7 ±0.8	6.10
G. retinervis	*0.4 ±0.1*	*2.1 ±0.1*	*2.0 ±0.3*	*2.3 ±0.2*	*1.70*
M. sericea	*3.4 ±0.2*	*3.9 ±1.3*	*6.7 ±0.9*	*6.5 ±1.2*	*5.13*
T. sericea	0.1 ±0.1	0	0.1 ±0.1	0.8 ±0.1	0.25
Total	100	100	100	100	100

spring. Species of woody plants occurring in their diet included *G. flava, G. retinervis, M. sericea, C. gratissmus, D. cinerea, B. petersiana, B. albitrunca* and *A. gerrardii* (Table 5). The dominant grasses in their diet included *D. eriantha, E. lehmanniana, S. pappophoroides, U. trichopus* and *M. albescens.* Seasonally, the goats were found to concentrate on woody plants. Plant species composition of their diet tended to be similar throughout the year.

Plant species diversity in cattle, sheep and goat diets

Mean annual plant diversity for cattle, sheep and goats was 21.1% (Table 6). Seasonal species diversity was significantly (P<0.05) high in summer and low in spring. Seasonal mean plant species diversity for cattle, sheep and goats was 19.9, 20.8, and 22.5%, respectively.Diets of goats were highest in average species diversity and cattle were lowest. Plant species diversity in cattle, sheep and goats diet were higher during summer period and lower during spring.

Diet overlaps of cattle, sheep and goats in communal grazing range

Diet overlaps of any combination of two livestock species differed significantly (P<0.05) by season (Table 7). The overlaps ranged from high for combinations involving animals that share similar forage types (eg. cattle and sheep) to low for combinations involving different foraging habits (eg. cattle and goats). The overlap of diets was greatest during the dry periods (winter and spring) and

Table 4. Average relative densities (%; mean ± SE) of plant species in seasonal diet of sheep in free range grazing.

Plant species	Summer	Autumn	Winter	Spring	Mean
Grasses					
A. graciliflora	0.3 ±0.1	0.2 ±0.2	0.2 ±0.1	0.3 ±0.1	0.25
D. aegyptium	3.7 ±0.5	2.8 ±0.2	1.3 ±0.3	0	3.90
D. eriantha	13.1 ±1.0	13.8 ±0.6	11.9 ±0.8	10.6 ±0.6	12.35
E. lehmanniana	10.3 ±0.5	9.8 ±0.8	9.2 ±0.5	8.4 ±0.6	9.45
E. rigidior	6.7 ±1.3	8.4 ±0.5	8.4 ±0.6	9.3 ±0.7	8.20
Eragrostis spp.	0.9 ±0.1	0.8 ±0.1	0	0	0.43
M. albescens	13.0 ±0.7	11.2 ±0.4	12.7 ±0.6	6.9 ±1.3	10.95
M. repens	1.4 ±0.9	0.8 ±0.2	0	0	0.55
S. uniplumis	1.0 ±0.1	2.7 ±0.3	3.5 ±0.5	4.4 ±0.6	2.90
U. trichopus	16.3 ±1.2	13.4 ±1.1	12.5 ±0.7	7.8 ±0.9	12.50
S. pappophoroides	9.5 ±0.8	11.1 ±0.8	13.9 ±1.2	17.6 ±1.5	13.10
Forbs					
C. beinscensis	6.3 ±0.5	4.3 ±0.7	0.8 ±0.1	0	2.85
T. terrestris	4.7 ±1.4	3.4 ±0.8	0	0	2.0
Unidentified	0.2 ±0.1	0	0	0	0.05
Woody plants					
A. fleckii	0.2 ±0.1	0.4 ±0.1	0	0.5 ±0.1	0.28
A. gerrardii	0	0.8 ±0.3	1.4 ±0.8	3.4 ±0.2	1.40
B. albitrunca	1.5 ±0.4	1.8 ±0.4	2.8 ±0.4	4.5 ±0.4	2.65
B. petersiana	1.4 ±0.6	2.2 ±0.2	2.8 ±0.6	2.8 ±0.5	2.33
C. gratissimus	2.9 ±0.3	3.6 ±0.6	5.3 ±0.4	7.6 ±0.6	4.60
D. cinerea	1.2 ±0.2	1.6 ±0.4	2.1 ±0.1	2.8 ±0.2	1.93
G. flava	3.3 ±0.7	4.0 ±0.5	5.8 ±0.7	8.1 ±0.5	5.30
M. sericea	2.8 ±0.2	3.2 ±0.6	4.7 ±0.8	5.3 ±0.3	4.00
R. bravisponosum	0.5 ±0.1	0	0.7 ±0.1	0	0.30

lowest in during wet periods (summer and autumn) for each animal combination. The observed overlaps reflect seasonal influences as animals shift diets focus. Mean overlaps were highest during the dry period (40%) and lowest during the wet season (32%). Mean overlap was high for cattle vs sheep (52.2%) and lowest for cattle vs goats (16.65%)

Relative preference indices

Fifteen of the most frequently occurring herbaceous species in the diets of cattle, sheep and goats were compared with their respective frequencies of occurrence on the range to determine the individual species preference by the study animals (Table 8). Cattle preferred (RPI >2) five of the fifteen herbaceous species in the following order: *D. eriantha, S. pappophoroides, U. trichopus, M albescens* and *E. lehmanniana*. The relative preference order of sheep was *S. pappophoroides, D. eriantha, U. trichopus* and *E. lehmanniana*. Goats showed a weak preference (RPI 1 - <2) with the following order *S. pappophoroides, D. eriantha, U. trichopus* and *E. lehmanniana*. Therefore, the relative preference for cattle (grazer), sheep (mixed feeder) and goat (browser), showed the greatest potential competition for only four grasses (*D. eriantha, E. lehmanniana, S. pappophoroides* and *U. trichopus*). However, the relative preference indices of grasses found in goats tended to be low while the competition for the latter grasses tended to be high for cattle and sheep.

Eleven woody species were selected for comparison with their respective frequency on the range to determine ranks in the diets (Table 8). Competition for browse plant species tended to be less for cattle, sheep and goats compared to the grass component. In general, cattle and sheep tend to have a weak mean preference for browse species, however certain plants species had higher relative preference indices. Cattle and sheep preferred five browse species (*C. gratissimus, G. flava, M. sericea, B. albitrunca* and *B. petersiana).*Goat preferred seven of the browse species but browsed all but one of the ten

Table 5. Average relative densities (%; mean ± SE) of plant species in seasonal diet of goats in free ranging conditions.

Plant species	Summer	Autumn	Winter	Spring	Mean
Grasses					
A. congesta	0.3 ±0.1	0.2 ±0.1	0	0	0.13
D. aegyptium	0.3 +0.2	0.3 ±0.2	0	0	0.15
D. eriantha	4.5 ±0.2	4.4 ±0.2	3.4 ±0.1	3.3 ±0.1	3.90
E. lehmanniana	3.5 ±0.4	3.2 ±0.3	2.7 ±0.3	2.3 ±0.3	2.93
E. pallens	0.5 ±0.3	0.7 ±0.2	0.3 ±0.1	0.4 ±0.2	0.48
E. rigidior	1.2 ±0.2	1.3 ±0.1	1.5 ±0.1	1.5 ±0.1	1.38
M. albescens	3.4 ±0.2	3.5 ±0.1	2.8 ±0.2	2.9 ±0.1	3.15
S. uniplumis	0.7 ±0.1	0.9 ±0.2	0.6 ±0.1	0.9 ±0.1	0.78
*U. tri*chopus	3.4 ±0.4	3.6 ±0.3	3.8 ±0.2	3.5 ±0.3	3.58
S. pappophoroides	4.1 ±0.5	4.0 ±0.4	4.0 ±0.2	3.8 ±0.4	3.98
Unidentified	0.2 ±0.1	0.3 ±0.1	0	0	0.13
Forbs					
I*. daleoides*	0.4 ±0.2	0.3 ±0.1	0	0	0.18
S. cordifolia	0.3 ±0.1	0.8 ±0.1	0.5 ±0.1	0	0.40
T. terrestris	0.6 ±0.3	0.3 ±0.1	0	0	0.23
Woody plants					
A. fleckii	0.5 +0.1	1.5 ±0.1	0.8 ±0.1	0	0.70
A. gerrardii	4.1 ±0.2	3.9 ±0.3	4.3 ±0.5	3.8 ±0.3	4.00
B. albitrunca	6.6 ±0.4	7.1 ±0.2	8.4 ±0.8	7.8 ±0.4	7.48
B. petersiana	11.3 ±0.9	11.7 ±0.3	9.7 ±0.3	8.4 ±0.4	10.28
C. gratissimus	10.9 ±1.2	12.7 ±0.9	13.5 ±0.6	15.9 ±0.6	13.25
D. cinerea	13.4 ±0.4	13.5 ±0.9	12.9 ±0.5	11.9 ±0.7	12.93
G. flava	12.2 ±0.6	13.6 ±1.4	14.3 ±0.3	16.6 ±1.1	14.18
G. retinervis	2.1 ±0.4	2.2 ±0.2	3.1 ±0.3	3.4 ±0.2	2.70
M. sericea	9.6 ±0.3	12.2 ±0.7	13.6 ±0.4	14.9 ±0.7	12.58
R. bravispinosum	0.6 ±0.1	0.7 ±0.1	0	0	0.33
T. sericea	0.2 ±0.1	0	0	0	0.05
Unidentified	0.4 ±0.2	0.6 ±0.2	0	1.0 ±0.6	0.5

Table 6. Average plant species diversities (%) of seasonal diets of cattle, sheep and goats in free ranging grazing conditions.

	Livestock-Type				
Season	**Cattle**	**Sheep**	**Goats**	**Mean**	
	Summer	22.4^{a}	21.8^{ab}	24.5^{a}	22.9^{a}
	Autumn	20.9^{ab}	21.5^{ab}	22.7^{a}	21.7^{ab}
	Winter	19.2^{b}	21.2^{ab}	22.9^{a}	21.1^{ab}
Spring	17.1^{c}	18.7^{b}	19.9^{b}	18.6^{b}	
Mean	19.9	20.8	22.5	21.1	

Means within each animal species followed by the same letter are not significantly (P>0.05) different.

species (Table 8). The mean relative preference index for browse by goats was more than three times that of cattle and sheep. The greatest relative preference index for any plant species (likely to compete for) was that by cattle, sheep and goats for *G. flava, C. gratissimus* and *B. albitrunca.*

DISCUSSION

The microhistological technique is a useful tool for estimating the botanical composition of livestock diets. As reported by Storr (1961); Free et al. (1970); Soder et al. (2009)*;* Kilonzo et al. (2005), the technique was also

Table 7. Seasonal diet overlaps (%) of cattle, sheep and goats in free ranging grazing conditions.

	SEASONS				
Animal	**Summer**	**Autumn**	**Winter**	**Spring**	**Mean**
Cattle vs sheep	47^{b}	44.7^{b}	59.3^{a}	57.8^{a}	52.2
Cattle vs goats	14.3^{b}	16.3^{b}	15.0^{b}	21.0^{a}	16.65
Sheep vs goats	38.1^{a}	35.0^{a}	37.0^{a}	41.2^{b}	37.5

Means between the seasons followed by the same letter are not significantly (P>0.05) different.

Table 8. Relative preference indices (RPI) of herbaceous and browse plant species occurring in cattle, sheep and goats diets for vegetation in free – range grazing.

Herbaceous spp.	Cattle	Sheep	Goats
A. congesta	0.1^{d}	0^{d}	0^{d}
A. gaciliflora	0.3^{d}	0^{d}	0^{d}
D. eagyptium	0.35^{d}	0.21^{d}	0^{d}
D. eriantha	5.58^{a}	3.74^{b}	1.23^{a}
E. lehmanniana	2.11^{c}	2.21^{bc}	1.02^{a}
E. rigidior	1.7$_{cd}$	1.51^{c}	0.91^{b}
M. albescens	2.6^{bc}	1.75^{c}	0.53^{c}
P. squarrosa	0.01^{d}	0^{d}	0^{d}
M. repens	0.03^{d}	0^{d}	0^{d}
S. uniplumis	1.89^{cd}	0.94^{d}	0.50^{c}
S. pappophoroides	4.02^{b}	4.52^{a}	1.38^{a}
U. trichopus	3.4^{b}	2.26b^{c}	1.2^{a}
C. beiscensis	0.01^{d}	0.53^{d}	0^{d}
S. cordifolia	0^{d}	0^{d}	0.12^{c}
T. terrestris	0.13^{d}	0.10^{d}	0^{d}
Mean	**1.48**	**1.18**	**0.45**
Browse spp			
A. fleckii	0^{d}	0.02^{d}	1.20^{c}
A. gerrardii	0.01^{d}	0.02^{d}	4.20^{c}
B. albitrunca	2.87^{a}	2.90^{a}	6.71^{b}
B. petersiana	0.91^{a}	1.21^{c}	3.01^{d}
C. gratissimus	2.27^{ab}	2.25^{b}	8.68^{a}
D. cinerea	0.01^{d}	0.05^{d}	4.71^{c}
G. flava	2.93^{a}	3.04^{a}	6.90^{b}
G. retinervis	0.05^{d}	0^{d}	1.05^{e}
M. sericea	1.92^{b}	1.40^{c}	3.57^{cd}
R. bravispinosum	0^{d}	0.03^{d}	0.91^{e}
T. sericea	0.01^{d}	0^{d}	0^{d}
Mean	**0.99**	**0.99**	**3.73**

Means within each animal species followed by the same letter are not significantly (P>0. 05) different.

found to under-estimates the epidermal tissues of forbs in the diet of livestock in this study. The study also revealed that high quality and more availability of forage during the growing period permitted animals to select a wider range of plant species with little or no risk of nutritional stress.

Seasonally, cattle diets were dominated by grasses.

This emphasized the feeding habit of cattle as mainly grass feeders. However, some plant species were utilized more than others. Animal foraging habits changed as the dormant seasons approach and shifted their diets to include woody plants because of the decline in herbaceous quality and loss of most of the ephemeral annual biomass. Villalba and Provenza (2009) stated that under natural conditions where plant diversity is the rule, not the exception, eating a variety of foods is how the animals meet their nutritional requirement.

More woody species occurring in livestock diet during the dry periods are in agreement with various workers (Le Houerou, 1980; Ramirez et al., 1993; Ngugi et al., 2004; Katjiua and Ward, 2006). Omphile (1997) reported that greater quantities found in the diets of buffalo and zebra during the dry seasons, reflect a period during which grass was less available in quantity and low in quality and animals may then supplement their diet from woody plants. The dominance of woody species in the diet of goats across the seasons confirms that this species is a browser (Le Houerou, 1980; Ramirez et al., 1993; Ngugi et al., 2004; Mkhize et al., 2014). The ability of selectively foraging on browse all the year round ensures them of continuous supply of a high quality diet (Omphile, 1997; Ngugi et al., 2004; Mkhize et al., 2014). Goats can withstand conditions were natural vegetation has degenerated because of overgrazing or bush encroachment while populations of grazers, such as cattle decline (Moleele, 1998), because goats probably exhibit an opportunistic feeding strategy (Le Houerou, 1980). While it is likely that the decline in quality of the available forage would negatively affect the nutritional status of the animals, it is not clear whether animals consciously select the most nutritious forages available in this study. Decrease in their N, P and increase their fibre content from wet to dry season appear to be related to maturity of current year's growth. A commonly used approach in livestock production is to supplement the deficient nutrients by feeding enhanced supplements if the natural forage does not meet the nutritional needs of the animals.

Cattle did not prefer plant species in order of availability, as the most highly ranked grasses in their diet were not the most available (g/m^2) on the range. For example, *S. pappophoroides*, one of the most highly preferred in the diet of cattle, was not only among the least common on the range, but also the least available in terms of biomass. On the other hand, *S. uniplumis*, one of the less preferred species was one of the most frequently occurring and most available (g/m^2) of all the herbaceous species throughout the year. These results concur with those revealed by Hu et al. (2014). Differences between the mean wet and dry season's biomass of annual grasses were primarily due to early cessation of growth and ultimate death of plants, which, coupled with grazing pressure, led to significant reduction in the average biomass of individual annual grasses.

Cattle and sheep are more negatively affected by drought because herbaceous plants are more sensitive to periodic moisture stress than woody plants. On the other hand, goats can better withstand drought periods with a relatively fewer browse species in their diet because browse plants are more nutritious and succulent and therefore less sensitive to drought. In addition, their ability to forage selectively on younger and high nutritious plant parts allows them a competitive edge in surviving periods of below average forage supply. This means that goats can withstand harsh conditions better than cattle or sheep.

Diet overlaps were generally low throughout the study period. These can, however, be expected to increase during periods of forage scarcity when opportunities of forage selection are restricted by limited species diversity and availability. Overlaps tended to be low during the growing seasons and high during plant dormancy seasons due to the reduced plant diversity and availability. Competition for forage between cattle, sheep and goats occurs more often during the dormant seasons and is more pronounced during years of subnormal rainfall where forage supply is low. Overlaps of diets during the growing seasons are less likely to result in serious competition for forage between animals, than overlaps occurring during dormant seasons, because forage biomass is abundant during the growing seasons.

Conclusion

Season was the main factor affecting herbage biomass availability and quality. Forage quality decreased from wet to dry season with greater declines in grasses than browse. Browse therefore, constituted a necessary and adequate supplement to herbage during the dry seasons, as dry season grasses are extremely deficient in most nutrients needed to meet livestock maintenance. Although it appears little can be done on seasonal decline in nutritional quality of forage, however some commonly used approaches in livestock management systems are as follows: a) Supplement the deficient nutrients by feeding enhanced supplements, b) Rangeland fertilization and especially brush management (e.g. prescribed burning to stimulation regrowth) may also be practical and profitable considering the economic value of livestock and c) Encouragement of those plant species in the rangeland that have above level of protein, by using certain grazing systems or range manipulation should be encouraged. Consistent monitoring of forage availability should be done in conjunction with monitoring of animal numbers and their respective needs for forage so that where necessary destocking can be based on sound scientific grounds to maintain the carrying capacity. Wet season diet of cattle and sheep were primarily herbaceous. Less selective livestock such as cattle, suffer more from poor diet quality during dry season compared to selective feeders such as goats that predominantly browse throughout the year and include fewer species of grasses. The potential for forage competition was higher throughout the year between cattle and sheep than between goats and cattle or between goats and sheep. A reduction in cattle numbers should enhance forage availability for sheep, and vice versa, but reducing the number of sheep or cattle have little or no effect on the foraging behavior of goats.

Conflict of Interest

The authors have not declared any conflict of interest.

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Determinants of intensity of market participation among banana traders in western Kenya

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Traders both wholesaler and retailers play a significant role in banana markets. In Kenya the banana market is not fully developed. This demands targeted studies to assess their performance. This study aims at examining banana traders' intensity of participation in the markets and constraining factors. A survey was conducted in 2013 in four counties. One hundred and ninety traders were randomly selected using multi-stage sampling technique. Data were collected on personal, market parameters, and institutional factors. Descriptive statistics and Tobit model were utilized in the analysis. The results showed that traders received market information from multiple sources probable to check on the reliability and accuracy. The results of the Tobit regression showed that the age and sex of traders distance to markets, type of banana and information sources significantly influence the volume of banana fruits handled by traders. Therefore based on the study findings, some of the suggested policy recommendations include; the need to foster development of banana infrastructures and also efforts should be geared towards improving market information sources among traders.

Key words: Banana traders, market participation, tobit model, Kenya.

INTRODUCTION

Markets are driving forces to increasing production and productivity of any farm enterprise like banana. Subsequently markets contribute to economic growth at both household and national levels. The growth of agricultural based economies like that of Kenya are dependant of markets (Republic of Kenya, 2013). This implies that enhanced agricultural production should be accompanied by improving output and input market considerations. This change occurs at household, regional and national levels. Since independence, the policy of Kenya government has been to enhance food security and poverty reduction. As manifested in all Development Plans since 1963 to Vision 2030, the emphasis of has been on food security, poverty eradication and health for all (Republic of Kenya, 2007). Banana enterprise has been one of the food crops that contribute to food security in the country (Njoroge et al., 2013). The acreage and production of the crop has progressively increased over years as shown by Republic of Kenya.

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It is imperative that self-sufficiency in food production is now an important political-economic goal of the many governments including Kenyan (Watson, 2013). The central Government and now the County Government have intentionally invested in banana productivity increasing strategies. About two decades ago. Some of the interventions targeted smallholder farmers. There are a number of government interventions in banana production. Such intervention included the tissue culture banana technology which was developed to enhance production targeting smallholder farmers (Wambugu and Kiome, 2001). This intervention coupled with other agronomic technological components addressed the supply side of the banana value chain by progressively increasing banana production over years. However, the banana market development has not grown in tandem with production (Mwangi and Mbaka, 2010). This implies that despite efforts of some market stakeholders to enhance its marketing, banana markets has not been good (Wanjiru et al., 2013).

Middlemen play a key role in banana marketing. They are categorized in two major groups; the merchant and agent middlemen. The agents perform distribution functions and they receive commission for the work done for consumers, wholesalers and producers. The merchant middlemen own the goods they sell and also bear the risk involved in marketing them. They stand to make profits or losses from the sale of the goods. The two main types of merchants who are involved in banana trade are wholesalers and retailers.

It is hypothesised that trader (retailers and wholesalers) participation in banana market is important because they promote banana distribution and subsequently promote the upgrading of technologies. The trader (wholesalers and retailers) participation in banana markets has not been fully documented not only in Kenya but also in the east African region. In addition banana markets are not well in Kenya developed unlike other cereal crops like maize, wheat, rice and beans for many years. Market participation is regarded as the participation of any stakeholder (as the wholesalers, retailers, processors or consumers) in any market related activity which promotes the sale of produce. This study was designed to identify determinants of level/intensity of banana market participation among banana traders in western Kenya; and identify constraints faced by traders. It is believed that banana production, marketing and consumption are crucial for all value chain actors in banana sub-sector.

The number of traders and volume of banana fruits traded are increasing over years. This is manifested presence of fruits in super markets, and street/roadside involvement in the trade. However, most research has given emphasis on farmer participation in markets in Kenya and outside Kenya (Chegea et al., 2015; Fischer and Qaim, 2011, 2012) but limited work on traders' banana trade. This is against the background that the banana traders and volumes of sales could be increasing over years. Traders play significant roles in transportation and distribution of goods to distant markets where the products are in scarcity. The market participation studies have used a number of techniques which included logit, probit and tobit (Adenegan et al., 2012).

MATERIALS AND METHODS

Study area description

The study was conducted in Trans Nzoia, West Pokot and Uasin Gishu in North Rift region and Bungoma and Busia counties in Western Kenya, while Kisii was in Nyanza region with diverse agro-ecological zones (Jaetzold et al., 2005). Banana is one of the emerging crops in the county occupying varying proportions of agricultural land. Trans Nzoia County is the main maize producing and exporting region in Kenya. It is located at latitude 0°52´-1°18´N, and longitude 34°38´-35°23´E. The human population is about 818,757 and a density of 741 persons per square kilometre (Republic of Kenya, 2010). The County covers an estimated area of about 1,559 km^2 with a bimodal rainfall pattern with a rainfall amount ranging from 1,800 to 1,900 mm. The County is covered by three main agro-ecological zones which include: Upper humid (UH), Upper midland (UM) and Tropical alpine (TA) zones. The altitude ranges from 1,000 to 1,200 m above sea level.

Bungoma County lies between latitude 0° 25.3' and 0° 53.2' North and longitude 34° 21.4'East and 35° 04' East. It covers an area of 2,068 km^2, which is about 25% of the total area of the province. The altitude ranges from about 2,000 m above sea level to 1,200 m. The county has a two-season rain regime, the long rains covering March to July while the short rains start in August to October. The average precipitation ranges from 1250 to 1800 mm with the central and north areas receiving a higher mount. The population of the district is estimated at 1,630,934 million in 2009.

West Pokot county lies between Latitudes 1° 10' and 30° 40'N and Longitudes 34° 50'and 35° 50'E. The district has a total area of 9,100 square. Altitude ranges from 900 m to about 3,000 m. Rainfall is bimodal with the long rains falling between March and June and the short rains occur between Septembers to November. The rainfall amounts range from 700 to 1600 mm. Temperatures ranges from 9 to 30°C. The district has a population of 512,690 people with a density of 37 persons per square. The greatest challenges are endemic poverty and food insecurity that renders the community dependent on food aid on annual basis. Agriculture has a huge potential for providing viable livelihood options to West Pokot people and thus alleviating the high poverty levels in the county. The potential also exists of transforming the pastoralist nomadic lifestyles to a sedentary one thereby impacting on planning for social amenities. The county is known for the production of banana and other fruits trees, maize, beans, potatoes, sorghum, finger millet, dairy, and beef (Wanyama et al., 2006).

Sampling procedure

A multistage sampling technique was used to generate market data. The target population composed of all traders involved in banana fruits trade in all the markets in western Kenya. The first stage involved purposive sampling of four counties based on levels of banana production and sell. Kisii and Bungoma counties were net exporters while Trans Nzoia, Busia, Uasin Gishu and West Pokot were net banana importers. The second stage involved random sampling of all active banana markets. The final stage involved the choice of the respondents using the linear systematic sampling technique. A list of banana traders (sample frame) was made with the help of local government officials (Ministry of Agriculture, Livestock Development and Fisheries staff and Count Government staff) who were in-charge of the various markets. The sample frame was established before the actual survey began in each market. The number of banana markets sampled were; 72 (Bungoma), 69 (Kisii), 27 (Trans Nzoia), 11 (Uasin Gishu), 6 (west Pokot and 5 (Busia). Sample size computations are important in ensuring that estimates are obtained with required precision. An estimated sample size of 190 were chosen using Cochran (1963)'s sampling formula (Equation 1) based on 2009 human population census (Republic of Kenya., 2009).

$$n = Z^2(1-p)p \Big/ e^2 \tag{1}$$

where *n* is the sample size, *Z* is the desired confidence level, *p* is an estimated proportion of an attribute that is present in the population in this proportion of banana traders in Kenyan markets, and '*e'* is the absolute size of the error in estimating '*p'* that researcher adopted. From previous studies and own experience it assumed that about 25% of all traders in western Kenya are engaged in banana trade. Against this background the sample size was computed at 95% confidence interval with ±3% margin of error. The sample size was approximately 188 traders (Equation 2).

$$n = \left((0.95^2(1-0.25)0.25) \Big/ 0.03^2 \right) \approx 190 \tag{2}$$

A semi-structured questionnaire was used to collect data. The data collection clerks were selected based on their good knowledge from on the local markets and banana markets. They were also selected on the basis of fluency in the local language/Kiswahili. They were trained for three days on survey design/implementation and allowed to pre-test the questionnaire in the neighbour markets that were not in the study area.

Data collection

The study was based on primary data collected through the use of structured questionnaire from a cross-section of cassava farmers. Data collected included demographic characteristics of the farmers; socio-economic, living standard and farm-specific variables; as well as income and expenditure variables.

Data for the study were collected from both primary and secondary sources. Primary data were collected through the use of structured questionnaire, personal interviews and direct observations were conducted. Data for banana traders (wholesalers and retailers) included quantities of banana fruits sold, market cost and selling prices, pricing strategies, sources of banana products, problems encountered, market information sources, market channels, personal characteristics of traders, distance to markets, sources of funds and personal characteristics of traders. Data collected were analyzed using descriptive and inferential statistics. The descriptive statistics such as frequencies distribution and percentages, mean, standard deviation, and variance were used and Tobit model.

Tobit model specification

One of the major decisions of banana traders is how much of the banana fruits to sell influences the profits. The purpose of the study was to assess the factors that influence the level of magnitude of market participation among banana traders. It was hypothesized that trader characteristics, Institutional factors, bio-physical factors look at factors that influence the level of banana sales.

In consumer theory, utility is a relative measure of satisfaction after consumption of goods (eg banana fruits) or services. Utility functions give us a way to measure traders' preferences for capital accumulation and the amount of risk (by investment in banana business) they are willing to undertake in the hope of attaining greater wealth through banana sales. Traders make decisions about what crop to trade, how much to trade, when and where to establish and sell the se; banana fruits in such a manner that they get maximum satisfaction.

Traders' behaviours are based on the basic idea that they aim at maximizing a utility function subject to availability of resources for investment (e.g. initial capital, market information, stores, education) or budget with which to satisfy benefits they receive. In this study the Traders maximize the utility (U_i) by buying and selling banana fruits (U_{Trd}). Thus, a trader rationally engages in banana trade if utility from profits received from banana trade is greater than a given threshold. The more the quantity sold the more the profits.

In this study the traders maximize the utility (U_i) by selling more produce to consumers (U_{Trad}) in an effort to maximize profits (U_π). Thus, a trader rationally sell more and more banana fruits if and only is total utility is increasing from the enhanced sales (TU_{sales}). This decision is influenced by a number of factors (U_X) (eg investment costs, sources of cash,) as shown in Equations (1).

$$Max - TU_{Trad} = F(U_X, U_{uo}) \tag{3}$$

Subject to resource (Cash, profits, and marketing strategies) constraints. Where TU_{trad} is the total utility derived from total banana sales, U_X is the banana sales while U_{uo} is the unobserved factors and *F* denotes function of. The Tobit model or censored normal regression model for situations in which *y* is observed for values greater than 0 but is not observed (that is, it is censored) for values of zero or less (Greene, 2003; Adenegan et al., 2012). The standard Tobit model is given in Equation (4).

$$Y_i{*} = \beta_0 + \beta_i X_i + \varepsilon_i \tag{4}$$

where ε $N(0,\sigma^2)$, Y_i*=quantity of banana sold in kg. These quantities were observed only for traders who participated in the market. β_{1i} =parameters to be estimated. ε_i=error term The independent variable specified as determinants of volume of banana sold/ intensity are defined as X_i. Thus *Xi* =vector of explanatory variables included in the model. The variables were hypothesized to affect the level of market participation. The variables were derived from empirical literature review (Kabunga et al., 2014) and researcher's reconnaissance experiences. With *Y* representing the volume of sales in kilogram while the X_i represents the explanatory variables where *Y* = Value of total banana produce handles and X_1 X_2, X_3,…, X_{19} were independent factors. They included; Log of age of HoH (LNintagres~1), banana selling price per bunch (LNq11sellp~2), log of distance to the nearest market (LNq6estdis~1), log of profit received by traders (LNprofit), used loan as initial source business (aqrdln), friends as initial source of cash for business (srcfnd), sex of trader (sxown), other traders as market information source (othertraders), use phone as market information source (phones), ripening banana (ripening), Kisii banana markt (kisicode), western region (westcode), primary level of education for trader (educrpim), secondary level of education for trader (educrsec), tertiary level of education for trader (educrtert), vehicle as main mode of transport (vehiclecode), bicycle transport as main mode of transport (bicyclecode), motor-cycle as main mode of transport (motocyclec~e) and Wholesale in banana (wholesaler)

Table 1. Definitions and hypothesized sign the variables.

Variable name	Description	Expected sign
LNintagres~1	Log of age of HoH (LNintagres~1),	±
LNq11sellp~2	Banana selling price per bunch(LNq11sellp~2),	+
LNq6estdis~1	Log of distance to the nearest market (LNq6estdis~1),	-
LNprofit	Log of profit received by traders (LNprofit),	+
aqrdln	Used loan as initial source business (aqrdln),	+
srcfnd	Friends as initial source of cash for business (srcfnd),	+
sxown	Sex of trader (sxown), 1=male; 0=female	+
othertraders	Other traders as market information source (othertraders),	-
phones	Use phone as market information source (phones),	+
ripening	Ripening banana (ripening),	±
kisicode	Traders in Kisii banana markt (kisicode),	+
westcode	Traders in western region (westcode),	+
educrpim	Primary level of education for trader (educrpim),	+
educrsec	Secondary level of education for trader (educrsec),	+
educrtert	Tertiary level of education for trader (educrtert),	+
vehiclecode	Vehicle as main mode of transport (vehiclecode),	+
bicyclecode	Bicycle transport as main mode of transport (bicyclecode),	+
motocyclec~e	Motor-cycle as main mode of transport (motocyclec~e)	+
wholesaler	Wholesale in banana (wholesaler)	+
awareness	Retailer (awareness).	+

and retailer (awareness). Several functional forms were fitted onto the data set in order to select one with best fit.

$$Y = 0....If..Y^* = \beta_0 + \beta_1 X_i + \varepsilon \leq 0 \quad (5)$$

$$Y = \beta_0 + \beta_1 X_i + \varepsilon ...If..Y^* = \beta_0 + \beta_1 X_i + \varepsilon \geq 0 \quad (6)$$

For ease of interpretation, the marginal effect for Tobit model was computed as shown given in Equation (8);

$$\frac{\partial Y}{\partial X} = \alpha\left(\frac{\beta_i X_i}{\sigma}\right)\beta_i$$

This is interpreted as a one unit change in an independent variable *Xi* and its effects on the observations (Table 1).

RESULTS AND DISCUSSION

Socioeconomic Characteristics of traders

The descriptive statistics of sampled traders are shown in Table 2. Out of 190 traders 97% were business owners and 3% were workers/managers. There were no significant differences between buying and selling prices for traders and wholesalers. However there was a positive price margin between the two levels for both traders. The wholesaler received a higher price margin (36%) compared to retailers (2%). The average age of the traders was about 40 years with wholesalers having a slightly higher age (40 years) than retailers (39 years). There was significant difference of the distance to banana sources between wholesalers (99 km) and retailers (41 km). This implies that probably transaction costs are high because of long distances to banana sources. The average period in business was 13 years with wholesalers having stayed in banana trade for more years (14 years) than retailers (12 years). Further analysis by gender revealed that there were more female traders than male traders. This implies that probably banana trade is more of a women affair than men. Majority of the business visited and interviewed were individually owned (96%) and about 4% were owned in partnership. Majority of both traders (>87%) interviewed had attained primary and secondary education and very few of them (2%) had post secondary education. There were significant differences ($p<0.05$) in the distribution of the proportion of traders who received loans for banana trade (wholesaler=28.3% and retailers=13.5%). This implies that very few traders acquired loans for business operations and this constraints growth in the entrepreneurship. Training is an important activity for banana trade to keep abreast of new trends and strategies to improve on business practices. There was significant difference ($p<0.05$) of the proportion of wholesaler and retailer traders who received business

Table 2. General characteristics of traders sampled.

Variable name		mean±sd			t-value	χ-square
		Full sample n=190	Wholesaler n=40	Retailer n=150		
Average buying price per bunch		229.7±18.2	220.1±20.5	257.6±38.8	0.90ns	…
Average selling price per bunch		298.2±25.5	300.0±	261.9±81.7	0.48ns	…
age of respondent		39.78±11.6	40.4±10.01	39.4±12.4	0.49	…
Distance to nearest market		64.2±11.5	98.7±33.7	40.6±9.2	2.33***	…
Period trading in bananas		13.2±9.7	14.3±10.1	12.4±9.7	1.18ns	…
% Respondent in West Pokot (N=6)		3.2	66.7	33.3		
% Respondent in Trans Nzoia (N=27)		14.2	18.5	81.5		
% Respondent in Bungoma (N=72)		37.9	20.8	79.2	…	15.67***
% Respondent in Uasin Gishu (N=11)		5.8	45.5	54.5		
% Respondent in Kisii (N=55)		36.3	45.5	54.5		
% Respondent in Busia (N=5)		2.6	20.0	80.0		
% Respondent Acquired loan (1=yes)		18.3	28.3	13.5	…	5.24**
% Respondent by sex of owner	Male	9.7	14.5	7.5	…	2.13ns
	Female	90.3	85.5	92.5		
% Respondent in by highest educational level	None	8.9	9.4	8.6	…	6.51**
	Primary	55.0	67.9	49.1	…	
	Secondary	34.3	20.8	40.5	…	
	Tertiary	1.8	1.9	1.7	…	
% attended any training in trade (1=yes)		13.2	23.6	8.4	…	7.61**
% Respondent in by banana business ownership	Individual	93.6	90.7	94.9	…	1.97ns
	Private company	3.5	3.7	3.4	…	
	Partnership	2.9	5.6	1.7	…	
% Aware of TCB technology (1=yes)		54.5	61.8	51.2	…	1.7ns

Source: Survey data, 2011/2012. Sd=standard deviation; ns=non-significant. *** Significant at 1% level, ** Significant at 5% level, *Significant at 10% level.

training. Out of 190 traders about 24% of the wholesalers and 8% of retailers received training in business entrepreneurship skills. Pooled analysis showed that out 190 traders of about 13.2% received training. This number is relatively low and demands for intervention in order to improve entrepreneurial skills in banana trade.

Market price information behaviour of banana fruits

Producers and traders are direct beneficiaries of the accurate and timely market information and equally timeliness of the same can benefit other actors like consumers. This trend may also lead to market efficiency and enhanced competition among chain actors. Subsequently, producers, traders and consumers require appropriate market information on the most current banana prices in the markets. In this study, banana information sources were diverse. About 52% of the sample traders used radio as their primary source of market price information (Figure 1.). The other 33% of traders got information by visiting the markets, 36% through Cell-phones and the remaining 24% traders got from other traders dealing with the same commodity (Figure 1). This implies that farmers did not rely on a single market information source but multiple. Probably they triangulate the prices from different sources to confirm the reliability and accuracy of the prices (Asiabaka and Owens, 2002). It is recognized that if banana traders had limited market and weak bargaining power partly due to limited market information and seasonality in production. These information sources are prone to low accuracy, inconsistent and delayed transmission for production and marketing decision.

Banana transportation

Effective banana distribution depends on efficient transportation system. The traders interviewed revealed that they used multiple mode of transport. This includaed; head-load (foot), bicycles, motorcycles, tricycles, cars and buses. Most of the traders (wholesaler and retailer) used vehicles (57 to 60%) and bicycles (17 to 33%) in the

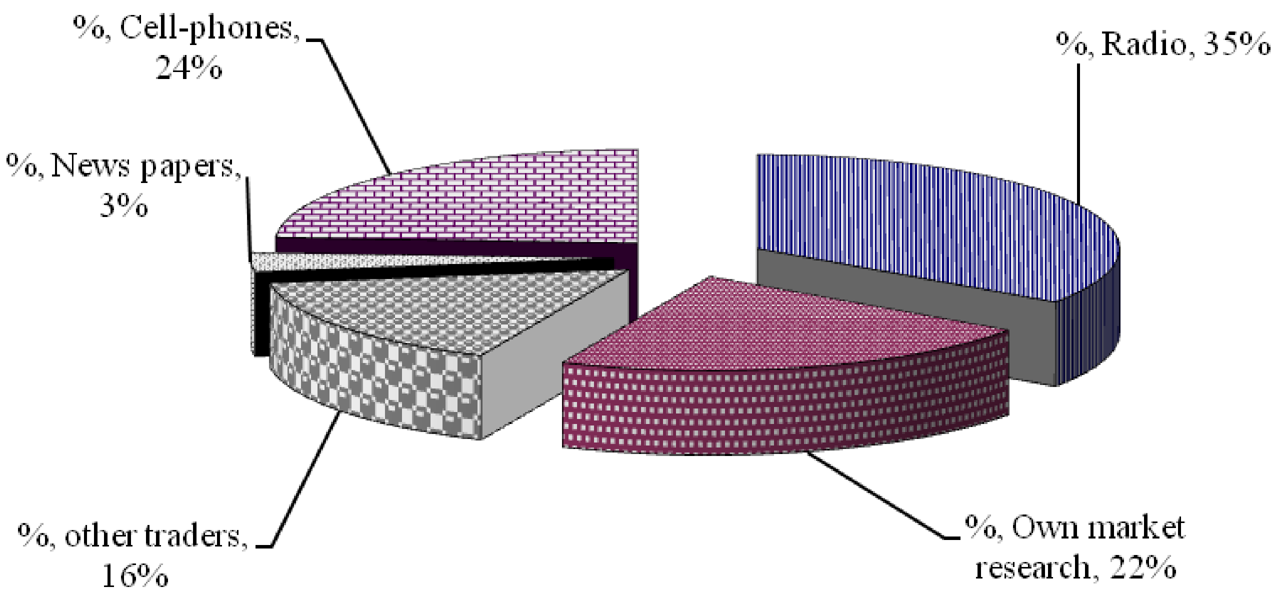

Figure 1. Market information sources of banana fruits for traders. Source: Survey data, 2011/2012.

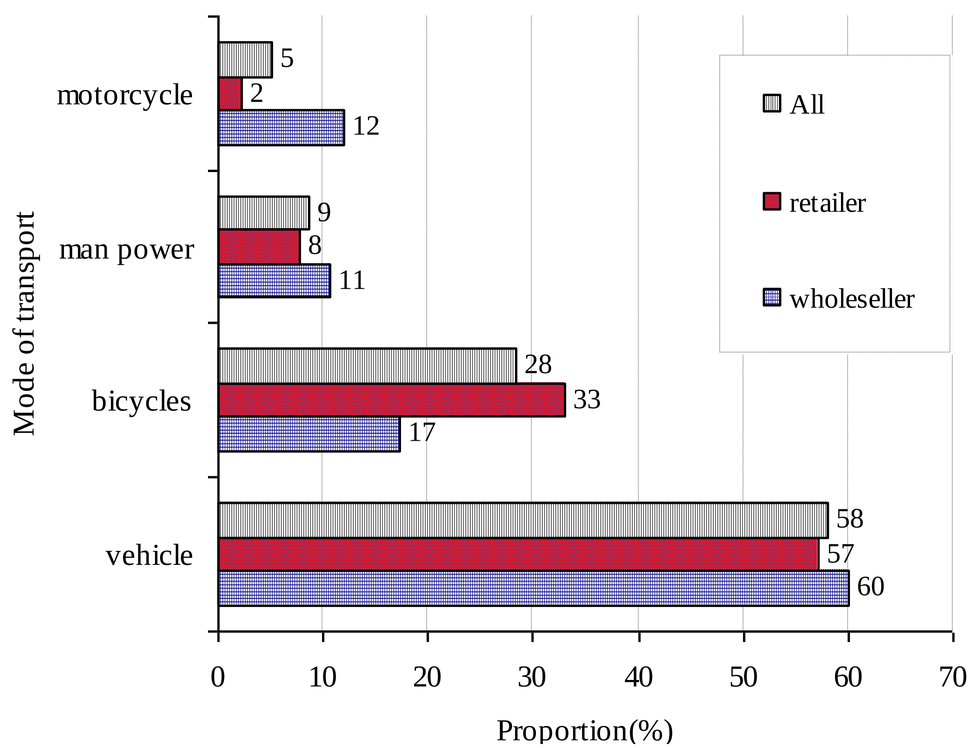

Figure 2. Percentage response on mode of transportation for banana trade. Source: Survey data, 2011/2012.

transportation of banana fruits and the least was motorcycles (2 to 12%) (Figure 2).The use of multiple mode of transport in metropolis and non-metropolis environments have reported by other authors (Emerole et al., 2007). Solutions to some of these problems require both public and private partnerships active involvement in

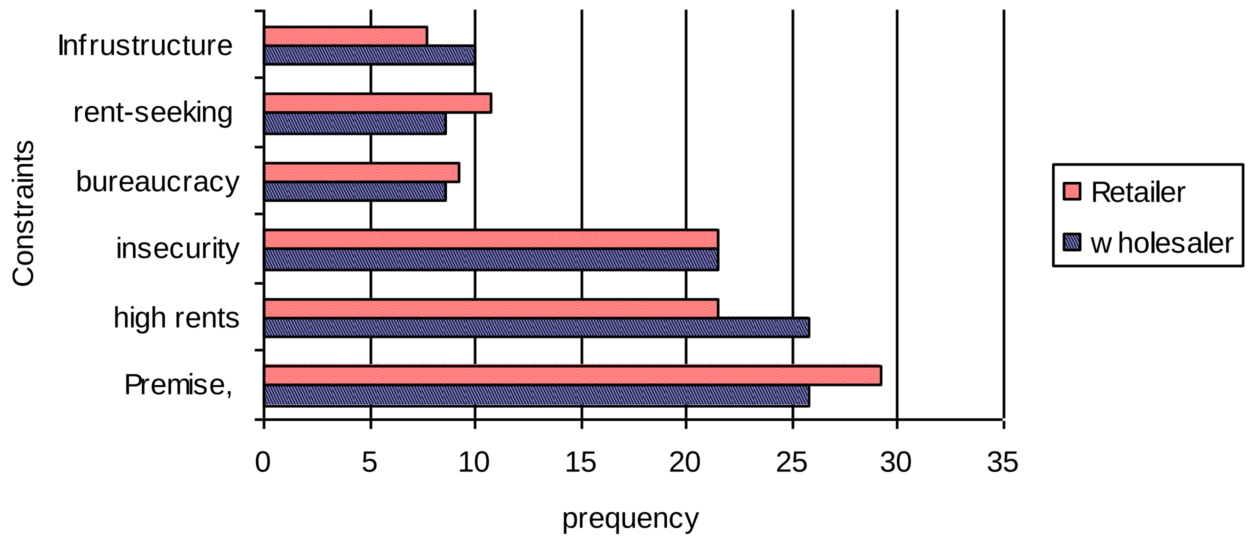

Figure 3. Constraints in banana trade. Source: Survey data, 2011/2012.

interventions. This implies the road infrastructure need to be improved as initiatives of increasing banana production by both County and National Governments.

Constraints to banana trade

The banana marketing system in western Kenya is afflicted with diverse problems. The problems noted by traders were: lack of premise, high rents, insecurity, bureaucracy and rent-seeking (Figure 3). Some of these problems have been raised in a number of studies in Kenya and outside outside (Kahangi et al., 2004; Republic of South Africa., 2012; Kasyoka et al., 2011). These constraints are likely to discourage expansion of banana trade in Kenya. Eventually farmers may not have incentives to invest in innovative technologies like Tissue culture banana. The County and National Government including the private sector support could be geared towards solving the problems for enhanced market efficiency. The use public and private transportation, camel and donkeys and their heads to transfer their goods across the borders to local and regional markets. Private transportation included animal-drawn carts, cars, small trucks and vans, and large trucks.

Determinants of market participation

The Tobit model results are presented in Table. Some variables were dropped during the estimation process because of multicolinearity. The Likelihood Ratio (LR) Chi-Square test is 52.43 with the p-value (that is, probability of obtaining the chi-square statistic value) of 0.000, meaning that at least one of the regression coefficients in the model is significantly different from zero since the values are less than 0.01. The results of the model revealed that only six variables were significant. The explanatory power of the specified variables as reflected by Pseudo R^2 value of the censored Tobit was 23.4%). This is relatively low but it is common among survey studies though this value is out side the values of 0.2 to 0.4 are considered highly satisfactory (Yoruk, 2011).

The coefficient of age of the traders had a negative and significant effect on intensity of banana sales. One percentage increase in the traders' age would decrease the intensity of banana sales by about 17%. This is probably because as traders increase in age they divest into other business activities other than banana.

The variable distance to banana market (LNq6estdis~1), was positive and significant, ($p\leq0.10$). One percentage increase in distance to banana fruits markets would increase banana sales by about 4%. The more the distance to the product markets sources the more banana sales handled by traders. This could be because traders who transport banana from far tend to use relatively big trucks for transportation. Bulk transportation reduces transportation cost per unit. Therefore, this demands for the good road systems network to give incentives for traders to engage in the activity. In addition there should be good packaging done to avoid losses. Similar observations on bulk transportation have been made by other authors (Wasala et al., 2015; Vigneault et al., 2009)

Being a male trader (sxown) reduces the likelihood increasing volume of banana sales compared to female traders. One percent increase in the proportion of male

Table 3. Determinants of market volume of sales/participation – The Tobit model.

variable name	Coef.(SE)	ME(SE)
LNintagres~1	-0.313(0.1794)*	-0.165(0.0946)*
LNq11sellp~2	-0.196(0.1872)	-0.103(0.0986)
LNq6estdis~1	0.072(0.0425)*	0.038(0.0224)*
LNprofit	-0.029(0.0334)	-0.016(0.0176)
aqrdln	0.110(0.1609)	0.059(0.0884)
srcfnd	0.026(0.0472)	0.014(0.0248)
sxown	-0.897(0.2067)***	-0.472 (0.111)***
othertraders	-0.561(0.1571)***	-0.315(0.095)***
phones	-0.110(0.616)	-0.056(0.302)
ripening	-0.378(0.190)**	-0.182(0.084)**
kisicode	-0.032(0.194)	-0.017(0.101)
westcode	0.241(0.178)	0.129(0.097)
educrpim	-0.255(0.198)	-0.135(0.105)
educrsec	-0.078(0.211)	-0.041(0.109)
educrtert	0.019(0.467)	0.010(0.248)
vehiclecode	0.065(0.188)	0.034(0.099)
bicyclecode	0.221(0.190)	0.119(0.105)
motocyclec~e	0.197(0.313)	0.1098(0.184)
wholesaler	0.533(0.156)***	0.311 (0.100)***
awareness	-0.119(0.136)	-0.063 (0.073)
cons	4.316(1.264)	1.822
/sigma	0.818(0.042)	0.7352
No. of obs.	190.000	
Prob > F	0.000	
LR chi2(16)=	52.43	
Prob > chi2	0.000	
Pseudo R2	0.234	
Log likelihood	-240.992	

ME=marginal effects, *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level. Source: Survey data, 2011/2012.

banana traders reduces banana sales by about 47%. Probably this could be attributed to the fact that there are more female banana traders than men who have specialized in the business. Similar arguments wereadvanced by Baden (1998) and World Bank (2012).

Market information sources are key performance indicators for traders as they may encourage/discourage agriculture value chain actors (Jack, 2013). The market information source from other traders (othertraders) had a negative effect on volumes of traded. This implies that those traders who relied on market information from other traders tended to sell less volumes of banana. This could be attributed to market competition among traders which lead.

Cooking and ripening (ripening) are the main types of banana consumed in green and ripe stages. The coefficient on type of banana dealt by traders was negative a significant. This revealed that trading in ripening types (ripening) tended to reduce the volumes of banana sold compared to dual and cooking banana. This could attribute to probably the low shelf life (and losses) of ripening banana which discourages traders from dealing in them. This may imply that probably traders dealing in more volumes of cooking banana compared to other types. This could be attributed to non-duality (sold as cooking and ripening) of the same unlike the cooking banana fruits. However, this is contrary to what was found by Kasyoka et al. (20011) that most farmers grew ripening banana which fetched high prices in the markets.

Being a wholesaler (wholesaler) enhances the likelihood of trading in larger volumes of banana compared to being a retailer. The wholesalers normally deal in large volumes probably due to the resource and experience they have compared to retailers. However, there some wholesalers who were also retailers and this enhances their ability to sell more volumes of fruits. Such strategies signify market vertical integration of wholesaler in an effort to enhance profit margins. This practice diminishes individual retailers' market power and profit margins as indicated by Nijs et al. (2009).

Conclusion

This study examined various characteristics of banana farmers in western, Kisii and north rift regions. Most of the trader's initial sources of funds was from their own sources followed by loans. Traders received market information from multiple sources probable to check on the reliability and accuracy. The traders also received banana fruits from multiple sources. The results of the regression showed that the age of the traders, sex of trader, distance to markets, type of banana and fellow traders as information sources, and wholesaling and mode of transport (motor vehicle and bicycle) used significantly influence the volume of banana fruits handled by traders. The multiple constraints identified require public-private active involvement. This implies that the interventions may be different in different regions. Some target zones and traders may demand increased production in order to enhance supply while other areas may not. The findings from this study also indicated the need to increase trader participation in banana trade as the volumes dealt were low. Therefore, based on the study findings, some of the suggested policy recommendations include the need to fostering development of banana infrastructures and effort should be geared at improving market information sources among traders.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

An interdisciplinary framework to study farmers' decisions on adoption of innovation: Insights from Expected Utility Theory and Theory of Planned Behavior

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This study presented a conceptual framework based on Expected Utility Theory (EUT) and Theory of Planned Behavior (TPB) to study farmers' decision on adoption of innovations. The framework explains the adoption decisions as a dynamic process, assuming a complex interaction of groups of variables coming from both theories. The combination of EUT and TPB overcomes some restrictions that arise when just one theory is used to study the adoption decision.

Key words: Adoption, farmers' decisions, expected utility theory, theory of planned behavior.

INTRODUCTION

One of the concerns of agricultural economists is understanding and modeling the processes and consequences of decision-making among farmers (Willock et al., 1999). Since Griliches' (1957) pioneering work on farmers' decisions to adopt an innovation, this topic has been studied intensively. These studies have been conducted by separate lines of research, e.g. economic, sociology, psychology, marketing, agricultural extension and anthropology (Pannell et al., 2006). Therefore, most of the theoretical models on adoption of innovation have tended to present discipline guided explanations to the adoption decision, although adoption is subject to a combination of social, economic, psychological, as well as cultural factors (Boahene et al., 1999; Edwards-Jones, 2006). From a theoretical point of view, there is a gap in the literature providing a formal integration of sociologic, economic and psychological variables in the relevant models (Edwards-Jones, 2006).

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Then, how can these disciplines be linked to better comprehend farmers' decision on adoption of innovation?In this paper, innovation is defined as an idea, practice, or object that is perceived as new by an individual or other unit of adoption (Rogers, 2003). For instance, conservation practices, environmentally friendly innovations, agricultural best management practices, water conservation practices, etc. are all considered innovations.

The purely economic literature regarding farmers' decisions is based on normative theory and on the assumption that decisions can be modeled only in terms of the individual acting to maximize profit (Austin et al., 1998; Willock et al., 1999). However, this literature cannot capture the full complexity of farmers' decisions (Austin et al., 1998). Additionally, such models fail to recognize that farmers' behavior is not driven only by the maximization of profit (Willock et al., 1999). In the field of agricultural economics, farmers' decisions and behaviors have been studied by two main different approaches: one is based on purely economic models, where Expected Utility Theory (EUT) plays a central role. The second approach is based on socio-psychological theories, where psychological constructs explain farmers' behavior, for instance the decision to adopt an innovation. One of the most relevant theories used by researchers to understand farmers' behavior was developed by Fishbein and Ajzen (1975), the Theory of Reasoned Action (TRA). TRA was extended by Ajzen (1991), resulting in the Theory of Planned Behavior (TPB).

The aim of this paper is to present a conceptual framework based on EUT and TRA/TPB to study farmers' decisions on adoption of innovations. The present paper does not aim at reviewing all the variables that may influence adoption decision, but rather, classifying, integrating and rearranging them in a generic framework. A general review about variables that may influence the adoption decision is given in Wejnert (2002). A review about innovations in agriculture are given in Feder et al. (1985), Feder and Umali (1993), Knowler and Bradshaw (2007), Pannel et al. (2006) and Prokopy et al. (2008).

The framework is in line with Wauters and Mathijs (2013), who observed a rising interest by scientists in socio-psychological methods to study adoption decisions. They argue that this interest has been induced by a growing discontent with the use of classic variables in adoption studies. For instance, a recent meta-analysis found in Knowler and Bradshaw (2007) showed that such variables tend to be mostly insignificant. Therefore, we build upon earlier work, bringing insights from discipline guide models into a generic conceptual framework in order to allow scientists to better formulate research on the topic.

Theories to study farmers' decisions to adopt an innovation

Expected Utility Theory (EUT)

EUT states that a farmer compares the innovation with the traditional technology and adopts it if the expected utility from adopting exceeds the expected utility of the traditional technology (Batz et al., 1999). Although the utility function is unobserved, the relation between the expected utility corresponding to each alternative is postulated to be a function of the vector of observed variables and an error term (Adesina and Zinnah, 1993; Batz et al., 1999). Using econometric models, mainly logit, probit and tobit, empirical studies analyze the impact of different and diverse variables on individual adoption decisions (Batz et al., 1999).

Theory of Reasoned Action (TRA) and Theory of Planned Behavior (TPB)

These theories attempt to frame human behavior in a limited number of psychological constructs (Beedell and Rehman, 2000). Both theories assume that people's behavior originates from their intentions to perform a specific behavior (Hansson et al., 2012). Introducing behavioral intention models are restricted to those behaviors which may be considered to be under the volitional control of the individual (Burton, 2004).

In TRA, intention (BI) is determined by two central constructs, attitude (Aact) and subjective norms (SN) (Martínez-García et al., 2013). The original reason to include subjective norms in models was that individuals do not act independently of cultural/social influences, but are continually referring their behavior back to important reference groups (Burton, 2004). In addition to these constructs, perceived behavioral control (PBC) is also assumed to influence intention in TPB (Beedell and Rehman, 2000). These constructs are represented in the following equation:

$$BI = Aact + SN + PBC$$

Where, according to Beedell and Rehman (2000) and Wauters et al. (2010): *BI* is the intention to perform the behavior; *Aact* is the degree to which execution of the behavior is evaluated positively or negatively; *SN* refer to people's perceptions of the social pressures upon them to perform or not a behavior; and *PBC* is the perceived own capability to successfully perform a behavior;

Together, attitude, subjective norm and perceived control lead to a positive or negative intention to perform the behavior (Wauters et al., 2010). A positive intention may not result in execution of the behavior, namely in cases where - according to people's perceptions - there is not sufficient availability of required prerequisites in terms of capital, knowledge, skills and opportunities (actual behavioral control) (Wauters et al., 2010). The concept of perceived behavior control is included only in TPB (Beedell and Rehman, 2000).

Attitude, subjective norm and perceived behavioral control originate from behavioral beliefs, normative beliefs and control beliefs, respectively (Hansson et al., 2012). These beliefs are indirect measures of the respective constructs, as in the following equations:

$$Aact = \sum_{i=1}^{n} bs_i \; oe_i$$

$$SN = \sum_{j=1}^{p} nb_j \; mc_j$$

$$PBC = \sum_{k=1}^{q} cb_k \; pb_k$$

Where, according to Beedell and Rehman (2000) and Wauters et al. (2010): *bs* is a person's perceived probability that performing the behavior will lead to a particular outcome; *oe* is a person's subjective evaluation of how good or bad a particular outcome of performing the behavior is, that is what is the utility of the outcome to the decision maker; *i* is the ith outcome; *n* the total number of possible outcomes; *nb* is a person's assessment of whether important referents think he should or should not perform a behavior; *mc* a person's assessment of how much he wants to comply with the important referents, utility from complying with the referents; *j* the jth referent; *p* the total number of referents; *cb* is a person's assessment of the probability of the belief affecting behavior; *pb* is person's subjective evaluation of the power of the control belief to affect performance of the behavior; *k* the kth control factor; and *q* the total number of possible control factors.

METHODOLOGY

This study used a qualitative approach to review papers on the adoption of innovation in agriculture that use either EUT or the TRA/TPB. To identify the relevant papers on the topic of adoption of an innovation in agriculture, a comprehensive search in the databases, such as Scopus, Web of Science and Google Scholar, was used. After identifying the papers a desk review was conducted. The aims of the desk review were: first to identify which variables have been used to understand farmers' decisions on adoption of an innovation; second to categorize the variables in groups. After identifying and classifying the variables, a framework was developed to integrate and rearrange them in a generic framework, which uses insights from both theories.

RESULTS AND DISCUSSION

EUT and TRA/TPB papers are summarized on Tables 1 and 2, respectively. Papers that bring insights but not explicitly using EUT or TRA/TPB are also briefly discussed.

Table 1 shows that EUT has been used to study different types of innovations worldwide. One could expect that, since one of the main assumptions in EUT is that farmers have the objective to maximize profit, this theory would be used to study innovations that are expected to increase profitability. Interestingly, EUT is not only used to explain adoption of innovation that are expected to increase profitability, for instance in Wubeneh and Sanders (2006), but also to explain adoption of sustainable and conservation techniques.

Table 2 indicates that TRA/TPB have been used in agricultural economics with at least two objectives: Explain a generic behavior, for example conservation behavior (Beedell and Rehman, 2000) and entrepreneurial behavior (Bergevoet et al., 2004) or a specific one (Martínez-García et al., 2013; Reimer et al., 2012; Wauters et al., 2010). These theories have been used to explain different types of innovations mainly in developed countries. Instead of using the "decision" concept, TRA/TPB papers that study adoption consider farmers' decisions as a specific behavior.

Variables are categorized in the following groups: beliefs; perceptions about characteristics of the innovation; psychological constructs, encompassing intention, attitude, subjective norms and perceived behavioral control; farmers' objectives and goals; background factors, including farmer characteristics, household characteristics, farm characteristics, farming context and acquisition of information/process of learning.

Farmers' perceptions

Some papers that use EUT to explain the adoption decision include measures of farmers' perceptions as explanatory variables. These papers can be divided in two categories: Perceptions about characteristics of the innovation and perceptions about benefits, risks and costs associated with the innovation. To justify the use of perceptions about characteristics of the innovation in EUT models, Adesina and Zinnah (1993) argue that adoption (rejection) of innovations by farmers may reflect rational decision making based upon farmers' perceptions of the appropriateness (inappropriateness) of the characteristics of the innovation under investigation.

Table 1. Reviewed papers on EUT.

Authors	Type of Innovation	Country of application
Adesina and Zinnah (1993)	Rice varieties	Sierra Leone
Adesina and Baidu-Forson (1995)	Sorghum and rice varieties	Burkina-Faso and Guinea
Asfaw and Admassie (2004)	Chemical fertilizer	Ethiopia
Baidu-Forson (1999)	Land-enhancing	Niger
Boahene et al. (1999)	Hybrid cocoa	Ghana
D'Emden et al. (2006)	Conservation tillage	Australia
Jara-Rojas et al. (2012)	Water conservation practices	Chile
Kassie et al. (2013)	Sustainable agricultural practices	Tanzania
Kebede et al. (1990)	Fertilizers and pesticides	Ethiopia
Khan et al. (2008)	Techniques to control pests	Kenya
Mazvimavi and Twomlow (2009)	Conservation techniques	Zimbabwe
Negatu and Parikh (1999)	Wheat varieties	Ethiopia
Roberts et al. (2004)	Precision farming technologies	United States
Wubeneh and Sanders (2006)	Technologies for increase sorghum productivity	Ethiopia

Table 2. Reviewed papers on TRA/TPB.

Authors	Type of innovation or behavior	Country/region of application
Beedell and Rehman (2000)	Conservation behavior	United Kingdom
Bergevoet et al. (2004)	Entrepreneurial behavior	The Netherlands
Martinez-Garcia et al. (2013)	Improved grassland management	Mexico
Reimer et al. (2012)	Best management practices	United States
Wauters et al. (2010)	Soil conservation practices	Belgium
Willock et al. (1999)	Business and environmentally-oriented behavior	Scotland

Adesina and Zinnah (1993), Adesina and Baidu-Forson (1995), Negatu and Parikh (1999), Khan et al. (2008) and Wubeneh and Sanders (2006) tested the hypothesis that farmers' perceptions about characteristics or attributes of innovation impact on the decision to adopt it. Their results support that farmers' perceptions of innovation-specific attributes have a highly significant effect on adoption. The other perception group is based on the assumption that what is relevant is how farmers perceive benefits, risks and costs associated with the innovation. Roberts et al. (2004) used perceived benefits and costs associated with an innovation as a potential explanatory variable. Their hypothesis was straightforward: farmers who are more informed about the innovation, perceiving higher profits and lower costs are more likely to adopt it. Their results confirmed the hypothesis. These variables were measured by asking farmers about their perceptions about profitability of the innovation (benefit), the cost associated with the innovation (costs) and how they perceive the innovation as being important to them in the future. In addition to perceived profitability, Abadi Ghadim et al. (2005) in a model based on ideas from EUT, used farmers' perceptions of the riskiness of the innovation as another explanatory variable on adoption decision. Their findings support that this variable plays an important role on adoption, as well as perceived profitability.

Beliefs and psychological constructs

As expected, papers based on TRA/TPB always use beliefs and/or the psychological constructs intention, attitude, subjective norm and perceived behavioral control varying the emphasis in each of them and how they are measured (Burton, 2004). Regarding the application of TRA to explain adoption decision, Martinez-Garcia et al. (2013) used this theory to study farmers who were already engaged in the use of improved grassland management (innovation) in Mexico. They found that farmers' intention to continue to use the innovation was influenced by salient referents (mainly male relatives) as well as by their own attitudes, confirming TRA hypotheses. An example of application of TBP in adoption decision is found in Wauters et al. (2010). They studied adoption of soil conservation practices (cover crops, grass buffer strips and reduced tillage) by Belgian farmers. Their results showed that the most important factor regarding adoption was farmers' attitudes towards the soil conservation practice.

Farmers' objectives and goals

EUT and TRA/TPB approach farmers' objectives and goals in different ways. While in TRA/TPB the role of these variables is not explicit, in EUT farmers are viewed as having only the objective of profit maximization.

In EUT the main assumption is that the farmer acts to maximize his level of utility. As utility is difficult to measure, profit is usually used by researchers as a substitute for this concept (Edwards-Jones, 2006). By adding risk attitude, farmers maximize expected utility of profit, rather than the expected profit (Abadi Ghadim and Pannell, 1999). As a result of this argument, if an innovation has a higher expected utility of profit than the old technology, adoption will occur.

As the role of farmers' objectives and goals are not explicit in TRA/TPB, some authors try to include them in the models. For instance, Willock et al. (1999) used the TRA construct attitude and additional variables related to farm objectives to explain two generic farmers' behaviors (business and environmental). As expected by TRA, they found that multiple attitudes influence both behaviors. Interestingly, some of attitudes influence behavior directly, while others are mediated by objectives. Bergevoet et al. (2004) used TPB to explain entrepreneurial behavior of Dutch dairy farmers. Remarkably, they used farmers' goals instead of intention in a TPB model. Then, goals were considered to be formed by farmers' attitudes, subjective norms and perceived behavioral control and entrepreneurial behavior a result of farmers' goals. Their findings confirmed that goals are one of the determinants of farmers' behavior. Additionally, Greiner et al. (2009) in an exploratory study hypothesized famers' goals or motivations to be related to adoption of Best Management Practices (BMP). They found a correlation between farmers categorized in a group with the goal (motivations) of "conservation and lifestyle" and BMP adoption.

In summary, although TRA/TPB do not use objectives and goals explicitly as a determinant of behavior, some authors (Bergevoet et al., 2004; Willock et al., 1999) include these variables in their models to better predict farmers' behaviors, highlighting the importance of objectives and goals on decisions. Note that objectives and goals were not used to explain a specific behavior, but rather generic ones.

Previous literature on the topic has identified farmers' objectives and goals to be heterogeneous, including, for example: Material wealth and financial security, environmental protection and enhancement (beyond that related to personal financial gain), social approval and acceptance, personal integrity and high ethical standards and balance of work and lifestyle (Pannell et al., 2006). There are many other farmers' objectives and goals identified in the literature. A list with farmers' objectives and goals are given in Bergevoet et al. (2004) and Solano et al. (2001).

Background factors

Background factors are not explicitly used in TRA/TPB models. As highlighted by Beddel and Rehman (2000), a criticism of TRA/TPB is that variables like age, gender, social class, etc. are not explicitly included in models. For these authors, a counter point to this is that all such variables are included, implicitly, through their effects on attitudes and intentions.

One exception is found in Reimer et al. (2012). In a qualitative approach they studied the adoption of Best Management Practices (BPM) by farmers in the United States. They based their analysis on an extension of TPB, namely Reasoned Action Approach (RAA) (Fishbein and Ajzen, 2010). RAA claimed that beliefs come from background factors, for example individual characteristics and past experiences (Reimer et al., 2012). Reimer et al. (2012) divided background factors from RAA in three main categories: Farmer and farm characteristics and farming context. They hypothesized these groups of variables to influence farmers' perceptions about characteristics of the BPM, which in turn influence farmers' beliefs. Characteristics of practices were based on Rogers' (2003) Diffusion Innovation Theory. They found that perceived characteristics of BPM play a role in adoption. However, they did not find many links between personal demographics and practice perceptions.

In EUT variables related to farm, household and farmer characteristics, farming context, acquisition of information/learning process are expected to influence farmers' adoption decisions. As explained before, the utility function is unobserved but the relation between the expected utility of adopting an innovation is postulated to be a function of the vector of observed variables.

There are numerous published papers relating variables classified to background factors with the decision to adopt. Examples of these variables are presented on Table 3, but the list is not intended to be

Table 3. Variables that may influence adoption decision.

Variable	Group
Experience	Farmer characteristics
Risk aversion	Farmer characteristics
Age	Farmer characteristics
Village head	Farmer characteristics
Gender	Farmer characteristics
Education	Farmer characteristics
Farmers moral concerns and emotions	Farmer characteristics
Farmer health	Farmer characteristics
Farmer full-time	Farmer characteristics
Awareness of a problem that an innovation may solve	Farmer characteristics
Education of family members	Household characteristics
Family size	Household characteristics
Home consumption	Household characteristics
Relatives in and outside the village that a household can rely on for critical support	Household characteristics
Off-farm employment	Household characteristics
Illness or death	Households characteristics
Availability of resources (machinery, labor, etc.)	Farm characteristics
Income	Farm characteristics
Farm size	Farm characteristics
Land tenure	Farm characteristics
Distance to markets	Farm characteristics
Hired-Labor	Farm characteristics
Plot access	Farm characteristics
Credit	Farming context
Modern environment	Farming context
Agro-climatic conditions	Farming context
Subsidies	Farming context
Pests and diseases	Farming context
Contact with extension	Acquisition of Information
Participation in on-farm trials	Acquisition of Information
Participation in workshops	Acquisition of Information
Social Network	Acquisition of Information
Membership in farmers' groups or associations	Acquisition of Information
Farmers confident in skill of extension agents	Acquisition of Information

exhaustive. There are many more variables that could be classified under this broad category. Here, our aim is to present justifications why variables were included in previous models or, if no explanation is found, the expected sign of the variable on the adoption decision. For this reason, the discussion is based mainly on hypothesis rather than on results.

Years of experience is expected to be positively related to adoption, because it may influence the ability of the farmer to obtain, process, and use relevant information (Adesina and Baidu-Forson, 1995; Adesina and Zinnah, 1993). Lower risk-aversion is expected to increase the probability to adopt an innovation (Baidu-Forson, 1999). In addition, to be a head of a village is expected to positively influences the adoption decision (Adesina and Baidu-Forson, 1995). The expected sign on age is unknown: Older farmers have more experience and then are better able to assess the characteristics of innovations than younger farmers; or it could be that older farmers are more risk averse than younger farmers and have a lesser likelihood of adopting new technologies (Adesina and Baidu-Forson, 1995). The hypothesis regarding gender is that male-headed farmers are more likely to get information about new technologies and take risky business decisions than female-headed farmers (Asfaw and Admassie, 2004). The argument to justify the inclusion of education as an explanatory variable is that education enhances the ability of farmers to acquire, synthesize, and quickly respond to disequilibria, thereby increasing the probability of adoption of an innovation (Asfaw and Admassie, 2004). Therefore, the level of education is expected to have a positive sign on the adoption decision. Mzoughi (2011) studied the role of farmers' moral and social concerns on the adoption decision. He argues that moral concerns are those related to individuals' (intrinsic) ethics, such as personal satisfaction, and this is useful for our discussion. Mzoughi measured moral concerns by asking whether the farmer thinks that do not feel guilty about his own choices is important and if the farmer thinks that doing the right thing is important. Although Mzoughi's study does not use any theory, it brought the argument that farmers' moral and emotions influence the adoption decision. Moreover, Hounsome et al. (2006) observed that one of the potential factors neglected on adoption studies is farmer health. These authors conducted an exploratory study and found that farmer mental health is correlated to agri-environmental schemes adopted by farmers. Full-time farmers are more likely to adopt an innovation, especially when an innovation involves the partial substitution of management for other factors of production and is therefore more time-intensive (D'Souza et al., 1993). Farmer awareness of a problem that an innovation may solve is likely to increase the likelihood of adoption, for instance farmer awareness of ground water contamination increases the probability that a farmer will adopt innovations that help him solve this problem (D'Souza et al., 1993).

Oftentimes, the adoption decision is not necessarily made by the head of the household alone but also by other educated adult members of the household (Asfaw and Admassie, 2004). Therefore, in general, higher education levels of household members increase the probability of adoption (Asfaw and Admassie, 2004). Family size is expected to have a positive sign on the adoption decision (Jara-Rojas et al., 2012). In addition, home consumption is expected to be inversely related with adoption (Jara-Rojas et al., 2012). The sign of the number of relatives in and outside the village that a household can rely on for critical support is indeterminate but expected to influence the adoption decision. The reason is, as explained by Kassie et al. (2013), that households with greater number of relatives are more likely to adopt new technologies since they are able to share risks with relatives, decreasing excessive exposure to risk. However, having more relatives may reduce incentives for hard work and induce inefficiency, such that farmers may exert less effort to invest in technologies (Kassie et al., 2013). Off-farm employment by other households members has an indeterminate sign on the adoption decision, since labor outside the farm may allow better access to information about new technologies or the capacity to finance investments, but it may also divert time and effort away from agricultural activities, reducing investments in technologies and the availability of labor (Kassie et al., 2013). Mazvimavi and Twomlow (2009) argue that farmers who have recent experience with death or illness (HIV/AIDS) in their households are more likely to reduce the intensity of adoption of innovations based on farmers' access to labor and resources. One of the justifications to include income as an explanatory variable is that it is needed to purchase the inputs required to adopt an innovation (Boahene et al., 1999). The hypothesis regarding distance to markets is that the further away a village or a household lies from input and output markets the smaller the likelihood that they will adopt a new technology (Kassie et al., 2013). When an innovation is labor-saving, the use of hired labor on the part of the farm is hypothesized to be negatively associated with the adoption decision (D'Souza et al., 1993). Farm size is hypothesized to have a positive impact on the adoption decision (Adesina and Zinnah, 1993). Land tenure can also affect the adoption decision, because a farmer is likely to manage owed land more intensely than rented land and to preserve its productivity for future generations (Roberts et al., 2004). Better access to the plot increases the probability of adoption because it influences the availability of the innovation, the use of outputs and inputs markets and availability of information and support organizations (Kassie et al., 2013). Agro-climatic conditions, for example rainfall, is expected to influence adoption decisions and depends on the type of innovation. One reason to justify it is given by D'Emen et al. (2006), who studied the adoption of conservation tillage practice. They argued that "the soil moisture conservation benefits of no-till would be more apparent in a drier than average season, and that observation (learning) of these benefits on nearby adopters' properties would prompt non-adopters to either trial or adopt the technology in the following season". On the other hand, Kassie et al. (2013) hypothesized that favorable rainfall has a positively impact on decisions to adopt improved seed types and fertilizer use.

Farm liquidity and credit are hypothesized to have a positive sign on the adoption decision. Farm liquidity is justified because this variable increases the credit worthiness of households and their ability to undertake risky businesses (Asfaw and Admassie, 2004). In addition, access to subsidies facilitates technology adoption and then is hypothesized to have a positive sign on adoption decision (Jara-Rojas et al., 2012). It is hypothesized that the probability of adopting an innovation is higher in modern environments than in traditional ones (Asfaw and Admassie, 2004). In addition, the presence of pest and diseases are expected to influence farmers' decisions and the sign of this variable depends on the type of innovation (Kassie et al., 2013).

Contact with extension agents is expected to have a positive effect on adoption because exposing farmers to availability of information can be expected to stimulate adoption (Kebede et al., 1990; Osuntogun et al., 1986; Polson and Spencer, 1991; Voh, 1982). In addition, farmers' confidence in skill of extension agents is expected to have a positive sign (Kassie et al., 2013). Based on the innovation-diffusion literature, Adesina and Baidu-Forson (1995) hypothesized that participation in workshops is positively related to adoption by exposing farmers to new information. Farmers who are in a network of relation(s) with many previous successful adopters have access to a large information network and, therefore, will be more likely to adopt an innovation (Boahene et al., 1999). Farmers may acquire information about new technologies from their peers and therefore, to be a membership in farmers' groups or associations is hypothesized to be positively associated with adoption of innovations (Kassie et al., 2013). Finally, participation in on-farm experimental trials is hypothesized to be positively related to adoption (Adesina and Baidu-Forson, 1995).

Overlaps and gaps in EUT and TRA/TPB studies on adoption of innovation

It was identified an overlap between theories regarding attitudes coming from TRA/TPB and perceptions of benefits and costs from EUT. As explained before, attitudes originate from beliefs about the probability that performing the behavior will lead to a particular outcome and subjective evaluation of how good or bad a particular outcome of performing the behavior is Beedell and Rehman (2000). In practice, a positive attitude towards adoption emerges when a person evaluates that performing the behavior has higher probability to lead to positive outcomes (benefits) than to negative ones (costs). Important to note that benefits and costs may include more than only economic ones. Therefore, in the framework, attitudes and perceptions about benefits, risks and costs are included in one block, as presented on Figure 1. This overlap is also highlighted by Lapple and Kelley (2013) who argue that attitudes can be interpreted as equivalent to utility.

After reviewing previous papers based on EUT and TRA/TPB, it was identified some gaps in the literature when only one of the theories are used. While the role of farmers' objectives and goals is differently stressed in papers based on EUT and TRA/TPB, perceptions and background factors are manly used in papers based on EUT and beliefs and psychological constructs only in the ones that use TRA/TPB.

Papers based on EUT assume that farmers have only the objective of maximize expected utility of profit. These papers do not consider that farmers may have more than one objective and goal. In addition, EUT papers do not consider social pressure upon farmers to adopt an innovation, what TRA/TPB papers consider using the psychological construct subjective norms. On the other hand, papers that use TRA/TPB do not consider explicit background factors, specially the role of acquisition of information/learning process.

New framework on adoption of innovation

The framework explains the adoption decisions as a dynamic process, assuming a complex interaction of groups of variables as presented on Figure 1. To start the process, a farmer must be aware about the innovation. Awareness means that a farmer knows that the innovation exists and that it is potentially of practical relevance to him (Pannell et al., 2006). The framework starts with the assumption that a farmer is aware of the innovation. It is recognized that there are many variables influencing farmer awareness, mainly ones related to acquisition of information (Adegbola and Gardebroek, 2007). However, it is argued that as the framework is dynamic, a farmer that is not aware of the innovation may acquire more information and becomes aware of it.

If a farmer is aware of the innovation, he/she has the following options: immediately adopt, partially adopt or trial the innovation and do not adopt. In addition, for some innovations, there may be an additional step, in which a farmer may decide to modify the innovation in order to adapt it more closely to his individual conditions (Adegbola and Gardebroek, 2007).

As stressed by TRA/TBP, intention is a predictor for a specific behavior, and we keep this assumption. In our discussion, a farmer has the intention to adopt an innovation if he wishes consciously to adopt it. In TRA/TPB, attitude, subjective norm and perceived behavioral control originate intention and we also keep this assumption but with one modification: perceptions about characteristics of the innovation also influence farmers' intention to adopt.

In order to define characteristics of the innovation that are expected to influence intention and make the framework easier to follow we based on Diffusion Innovation Theory. In this theory there are five characteristics of innovations that affect adoption:

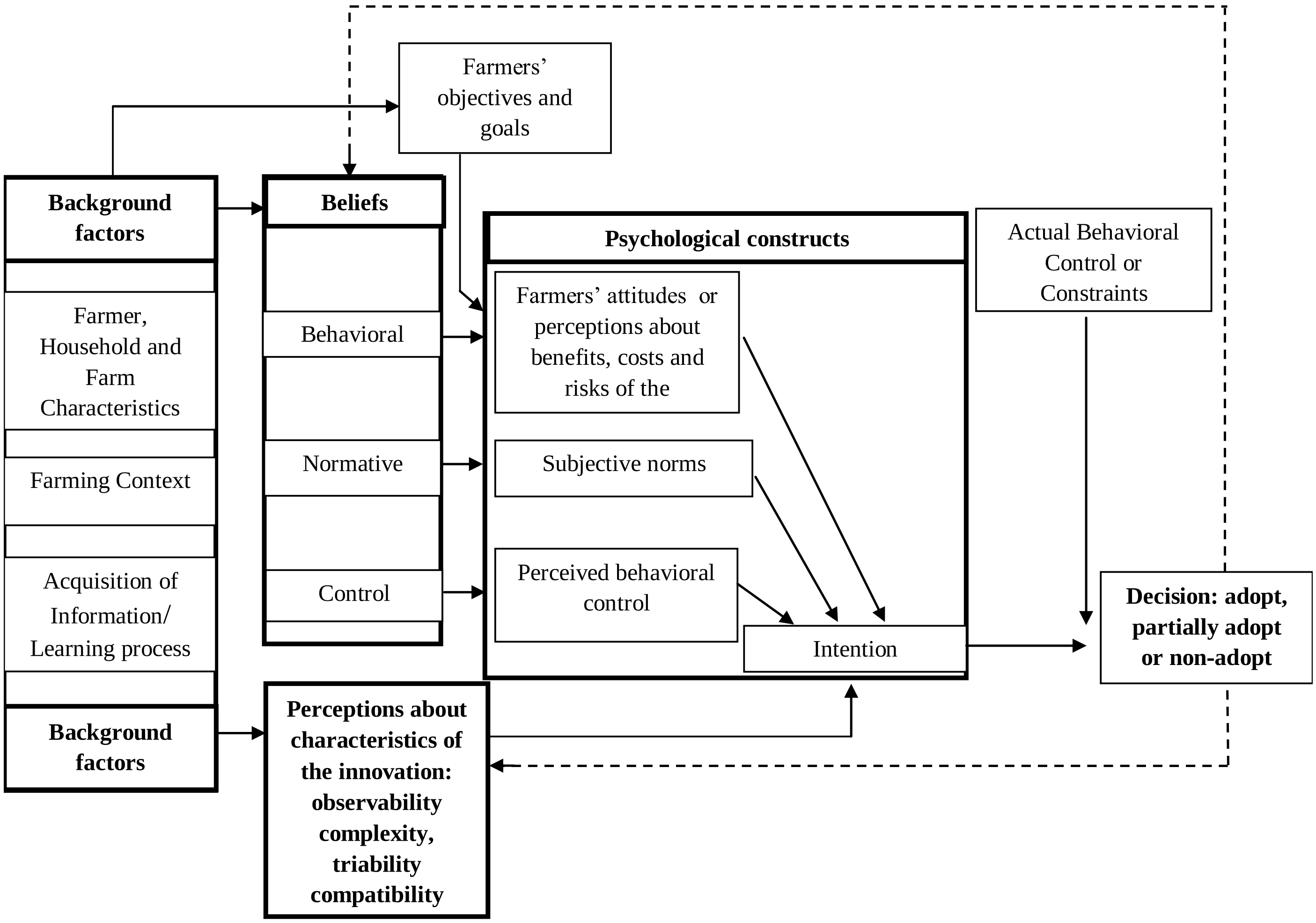

Figure 1. Conceptual framework to study farmers' decisions on adoption of innovation.

Relative advantage, compatibility, complexity, observability and triability (Rogers, 2003). The framework presents four, because relative advantage is already included in the framework in a different group of variables, namely attitude or perceptions about benefits, costs and risks. Rogers (2003) defines these characteristics as follows: Compatibility is "the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters"; trialability is "the degree to which an innovation may be experimented with on a limited basis; observability is "the degree to which the results of an innovation are visible to others; and complexity is "the degree to which an innovation is perceived as relatively difficult to understand and use".

As stressed by TPB, normative and control beliefs form the constructs subjective norm and perceived behavioral control, respectively. Attitude originates from behavioral beliefs and is hypothesized that objectives and goals also influence this construct. This hypothesis is explained because behavioral beliefs are related with a person's subjective evaluation of how good or bad a particular outcome of performing the behavior is (Beedell and Rehman, 2000). This hypothesis is exemplified as follows. A farmer that has the belief that an innovation increases profitability evaluates this outcome better if he has the objective of increase profit.

Together the psychological constructs coming from beliefs and perceptions will result in a positive or negative intention to adopt or not an innovation. However even when there is a positive intention, the adoption may not occur because there is insufficient availability of required prerequisites, that is, control beliefs or constraints.

Beliefs, perceptions and objectives and goals are influenced by variables coming from background factors encompassing three blocks: Farmer characteristics, household characteristics, farm characteristics; farming context; and acquisition of information/process of learning. Finally, it is expected that a famer who adopt or trial the innovation, modifies his beliefs and perceptions.

The framework brings some insights that must be considered in adoption studies. Farmers' are not expected to consider only expected profit as the benefit to adopt an innovation. Additionally to the trade-off between perceived expected profitability and perceived riskiness associated with the innovation, farmers may also consider other benefits, costs and risks, for instance, social and environmental ones to make the decision. An example of this argument is found in Khan et al. (2008). They asked farmers what were the benefits associated with adoption of "push–pull' technology for control of cereal stemborers and *Striga* weed in western Kenya. The main benefits of the innovation cited by farmers were reduced infestation by pests, improvement in soil fertility, increase in maize grain yields, improved fodder and milk productivity. This insight is exemplified as follows. Suppose that a farmer perceives that an innovation has a higher expected profitability (benefit) compared to an "old" technology that has been used by him. But he also perceives that there are other costs associated with the innovation that are not economic ones, for instance environmental. Then, although the innovation has a higher expected profitability compared with the "old" technology, a farmer does not adopt it because he perceives high non-economic costs.

Other insight is to make explicit the role of social pressure on the adoption decision trough the construct on farmers' subjective norms. A positive influence on his intention to adopt an innovation comes from beliefs that adopting will be supported by "salient referents". This argument is reinforced by Mzoughi (2011). He observed that social concerns drove farmers' adoption decisions, where social concerns are those "which shape the individual's behavior in relation to his/her reference group, for example, the other similar farmers in the same region."

In the framework it is also considered that farmers may have more than one objective and goal and these may vary in time. In addition, a farmer may not take all of his objectives and goals into account on adoption decision. Therefore, this point of the framework is more in line with some findings from the psychological approach. Instead of maximizing expected utility of profit we based on Simon's (1957) 'satisficing' concept. As explained by Burton (2004), this idea acknowledges that people do not necessarily engage in economically optimal decision-making, but instead may optimize social, intrinsic and/or expressive goals. This argument can be illustrated with the following example. A farmer has many objectives and goals, for instance he wants to have a high income, but also wants to have some leisure time and be recognized as leader in his community. When he makes the decision to adopt an innovation, he may take into account if the innovation helps him to achieve his objectives and goals. As time goes, he may change his objectives and goals and then an innovation that at the beginning was not expected to help him to achieve his "old" objectives may now be in line with the new ones.

Therefore, the framework's hypotheses are: a positive attitude about the outcomes of adoption, a positive evaluation about how important others support the decision (subjective norm), positive beliefs that one has the resources to adopt an innovation (perceived behavioral control) increase the probability to adopt it, by a positive impact on intention. In addition, a positive impact of observability, triability and compatibility is expected on intention, while complexity is expected to have a negative effect on intention. Moreover, a positive impact on farmer attitude is expected when the innovation is in line with farmer' objectives and goals and if the farmer considers them when making the decision.

Perceptions about characteristics of the innovation and the psychological constructs attitudes, subjective norms and perceived behavioral control result in a positive or negative intention to adopt an innovation. However, perceived benefits, costs and risks, important salient referents, perceived availability of resources, perception about characteristics of the innovation and farmers' objectives and goals may vary over time. Therefore, what is important is what are farmers' beliefs, perceptions and objectives and goals at the time of the decision.

In previous studies from EUT variables classified in the background factors were assumed to directly influence the decision to adopt or not an innovation. An exception is a framework on adoption of innovation developed by Abadi-Ghadim and Pannel (1999). These authors hypothesized that social and demographic factors, like age and experience, influence the adoption decision by influencing farmer's subjective perceptions, uncertainty and/or attitudes. Therefore, in the present framework these variables are not assumed to directly influence farmers' decisions, but they are expected to have an indirect impact on farmers' perceptions and beliefs, being somehow in line with Abadi-Ghadim and Pannel (1999) hypothesis.

Positive or negative impact of farmer, household and farmer characteristics and farming context groups depends on the variable itself and on which beliefs or perceptions are considered. For instance, it is expected that a farmer who has more experience also has more "correct" behavioral beliefs about the innovation. But it is also expected that experience influences perceptions about the characteristics of the innovation.

As a farmer acquires more information about the innovation by adopting it or partially adopting (trial) or other sources (workshops, social network, etc.) his perceptions and beliefs are expected to change, as highlighted on Figure 1. The relevance to the process of acquiring more information and learning in a dynamic framework were also stressed by Abadi-Ghadim and Pannel (1999), who showed in a formal model that information from trialling an innovation has two important aspects: skill improvement, and better decision making.

Conclusion

A detailed framework on the adoption decision has been presented. In order to bring useful insights for future studies on the topic, our concern was more related on how famers make decisions in practice, because, as observed by Öhlmér et al. (1998), most research on farmers' decisions has been conducted on how they should make decisions. It is important to recognize that the adoption decision depends on complex factors (Negatu and Parikh, 1999). Therefore, based mainly on empirical models that use EUT and TRA/TPB this dynamic framework highlighted what is already known, that the adoption decision is influenced by an array of variables. However, we argue that using only one of these theories, instead of a combination of both, may restrict researchers on their findings by not considering results from different approaches for the same topic. For instance, studies on adoption based on TRA/TPB do not consider explicitly the role of acquisition of information. Moreover studies based only on EUT assume that farmers' have the single objective of maximizing expected utility of profit. The combination of EUT and TRA/TPB overcomes the above-mentioned restrictions. We are aware that the way variables are grouped, especially in the background factors, may generate controversy. Other researchers could choose to group variables differently. The counter point is that what is important is the idea that those variables influence the farmers' adoption decision by having an indirect impact on their perceptions and beliefs, instead of by a direct impact as assumed by EUT studies. Finally, including all these variables and their interrelations in an empirical study is a considerable challenge. However, we consider that the framework provides a broad and comprehensive view of the adoption decision, allowing scientists to better formulate their research in this topic.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effect of deficit irrigation on yield and yield components of sunflower (*Helianthus annuus* L.) on Gezira clay soil, Sudan

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Sunflower has become an important crop for both farmers and consumers in Sudan. It is a crop that fits well in the local cropping system and is considered one of the most important oil crops of the country. Regular irrigation intervals could be reduced in order to increase total yield and maximize water productivity. In contrast prolonged irrigation intervals during sensitive growth stages may result in reduction in total yield. The application of water below the evapotranspiration requirements is termed deficit irrigation (DI). The experiments were conducted at Gezira Research Station, WadMedani, Sudan, in a randomized complete block design with three replications. In this study irrigation intervals every week (W) during the whole growing period, 10 days interval (F1), 15 days interval (F2) and 20 days interval (F3) after flowering stage and 10 days interval (S1), 15 days interval (S2) and 20 days interval (S3) after seed filling stage were applied to study the effect of full and deficit irrigation on yield and yield components of sunflower crop during the two growing periods 2011/12 and 2012/13. Results showed that water stress decreased the number of filled seeds per head, weight of full seed and seed yield. The highest seed yield of (3130 and 3140 kg/ha) was obtained from full irrigation (W) and the lowest seed yield of (2082 and 2130 kg/ha) from irrigation every 20 days after flowering stage in the first and second season respectively. Results indicated that there were no-significant differences on head diameter, plant height and stem diameter when water deficit occurred after the flowering stages. Lower WP of 0.21 to 0.26 and 0.21 to 0.27 kg/m3 were obtained when sunflower irrigated every 20 days after flowering and seed filling stages in the first and second season respectively. Results revealed that water productivity was low under Gezira conditions.

Key words: Water productivity, deficit irrigation, sunflower, seed yield.

INTRODUCTION

The Sunflower is a drought adapted crop with a short growing season that requires relatively low irrigation requirements and makes it ideal for areas with limited irrigation supplies. Sunflower (*Helianthus annuus* L.), is

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an important oil crop of the world as well as in Sudan. It is an edible oil crop in Sudan; the seeds have high oil content (40 to 50%) and 30% digestible protein. They can thus be used as a source of food for humans or as a poultry feed. Sunflower cake can be made as animal feed. It can be cultivated in winter season (November) under irrigation, as a winter crop and in rain-fed areas as a summer crop (July). In recent years the Sunflower cultivation area has increased in Sudan, because of the moderate cultivation requirements and high oil yield. The yield of crops that are cultivated under rainfed conditions in Sudan has progressively declined with time, owing to changes in both quantity and distribution of rainfall. There is a great need to increase crop production to meet the demand of the rapidly growing population. The importance of irrigation to enhance crop production in the water scarce conditions of Sudan is yet to be translated into sustainable development options for irrigated agriculture, which can potentially raise the yield of Sunflower to 5 t/ha.

Although experimentation on sunflower in Sudan started as early as the 1940s, the real concern with its commercial production started late, mainly as a rain-fed crop, where rainfall is very erratic in the amount and distribution. However, some rain-fed areas have experienced significant drought. This led to shifting Sunflower cultivation to irrigated areas. For this reason determining crop water requirement and water productivity under irrigated agriculture is essential for planning and water resources management. In the future irrigation management will emphasize on maximizing the production per consumed unit of water, the water productivity, rather than maximizing yield per unit of area in irrigated agriculture under water scarcity. The water requirement for the crop is the most important factor, because water has a direct effect on the yield of the crop. Karam et al. (2007) reported that the increase in the irrigation interval reduced seed yield, plant height, head diameter, seed oil content and increased the number of un-filled seed. Anwar et al. (1995) stated that the yield and yield components of Sunflower were affected by the number of irrigation water supplies. As the number of irrigation water supplies increased the days to maturity, seed yield and plant height increased. D'Andria et al. (1995) concluded that yield components of sunflower were affected by irrigation treatments.

Water stress, particularly at the flowering stage, reduces fertilization and seed set due to dehydration of pollen grains. More studies were focused on the effect of drought on Sunflower yield (Stone et al., 1996; Faisal et al., 2006; Karam et al., 2007). Also water stress at the flowering stage was observed to be a limiting factor for seed filling, so significant reduction of unfilled seeds was observed as a result of irrigation deficit. Pejić et al. (2009) summarized that the period from flowering to maturity was the most sensitive towards water deficit. Many researchers stated that an irrigation interval of seven days in Sunflower improved seed yield, oil yield and water productivity. Yawson et al. (2011) reported that, Sunflower is considered to be tolerant to water deficit to some extent. Therefore, knowledge of the effects of irrigation scheduling on sunflower production and water productivity under water stress conditions is becoming increasingly important. Irrigation scheduling is particularly important since many field crops are more sensitive to water deficit at specific Phenological stages. In the season where there is insufficient water for crop demand, the optimum use of irrigation water is essential for water resources management. Optimum use implies the efficient irrigation water use and proper timing of irrigation to face the critical stages of growth of the crop concerned. It is important to analyze the effect of water supply on crop yields. The effect of water stress on growth and yield depends on crop varieties, magnitude and stages of occurrence of water deficit. In this study the water stress was after starting of 50% of flowering and seed formation stage to assess to what extent the water will reduce the yield under different irrigation intervals. The objective of this research is to study the effect of deficit irrigation on yield and yield components of Sunflower, and to assess the water productivity.

MATERIALS AND METHODS

Study area

The experiment was conducted at the Gezira Research Station Farm, which is located between longitude 14 .4° N and latitude 33 5° E in WadMedani in central Sudan and at an altitude of 405 MSL (mean sea level) (Figure 1). In particular, the soil of the study area is a deep, heavy soil (Vertisols) with 58 to 66% clay, 0.05% organic matter, a water infiltration rate of 1 mm/h and pH of 8.5 (Table 2). All agronomic practices were conducted during the two growing seasons of 2011 and 2012. Sunflower, variety Hysun 33 was sown in the mid of November for the two seasons. The seed rate was three seeds per hole at 30 cm inter-row plant spacing and 80 cm between rows. The plant was then thinned to one plant per hole after two weeks. The experimental design adopted was randomized complete block design (RCBD). Fertilizer was applied in the form of urea at the rate of 46% N, 86 kg N ha^{-1} in two split doses, one with the second irrigation (with thinning) and the rest at the flower initiation as recommended by Agricultural Research Corporation (ARC). The plot size was 50 m^2 (10 m×5 m). After emergence the field was irrigated every week up to flowering stage and then on the basis of water deficit at three irrigation levels. Weeding was done by hand after third irrigation and repeated four times during the whole season.

The irrigation treatments were seven using the furrow method including every week (W), 10 days (F1), 15 days (F2) and 20 days intervals (F3) after 50% flowering to physiological maturity and 10 days (S1), 15 days (S2) and 20 days intervals (S3) during seed filling stage to physiological maturity which replicated three times. Water applied for each treatment was measured during the whole growing season using a current meter device which was placed in Abu vi (Abu vi is a small canal to deliver water to the experimental plot) to measure the discharge of the water to each plot separately. The total number of the plots was 21. Daily weather data were collected from the nearby meteorological observatory of Gezira Meteorological Station in WadMedani (Table 1). Also the reference

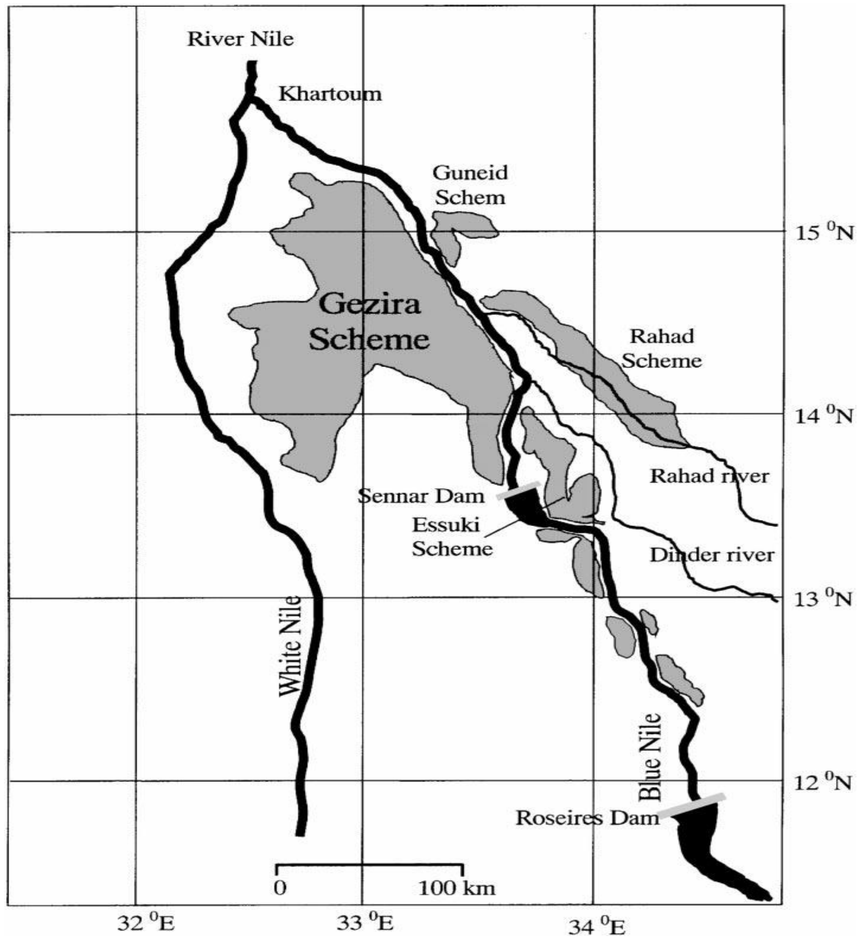

Figure 1. The location of the Gezira Scheme (Adopted from Abdelhadi et al. (2000).

Table 1. Mean monthly weather data of Gezira Research Station for the two growing seasons (2011/12 and 2012/13).

Month	Maximum temperature (ºC)	Minimum temperature (ºC)	Relative humidity (%)	Wind speed (m/s)	Sunshine (h)	ET0 (mm/day)
2011/2012						
November	35.8	15.5	35	1.9	11.2	6.0
December	35.6	15.2	31	1.9	10.8	5.6
January	33.9	15.3	30	2.3	10.5	6.1
February	37.7	19.1	28	2.5	10.3	7.6
March	38.9	19.8	24	2.5	9.9	7.9
2012/2013						
November	37.1	18.7	40	1.6	10.5	6.5
December	34.8	15.5	30	1.8	10.7	5.4
January	35.0	17.4	34	2.0	10.4	5.8
February	38.2	20.0	28	2.1	9.5	6.8
March	40.4	19.3	24	1.9	9.6	7.2

Source: WadMedani Meteorological Station (2013).

evapotranspiration for two growing seasons are plotted in Figure 2. Weeding was done by hand continuously during vegetative growth. Five plant samples were taken to determine the different crop parameters such as plant height (cm), head and stem diameter

Table 2. Soil chemical and physical characteristics of the experimental field.

Depth	Clay (%)	Silt (%)	Sand fine (%)	Sand Coarse (%)	Bulk density (g/cm^3)	Field capacity (vol %)	Wiliting point (vol%)	Organic matter (%)	pH
0 to 30	58	25	13	4	1.60	38.2	20.7	0.34	7.9
30 to 60	60	28	9	3	1.52	45.9	24.9	0.31	8.1
60 to 90	54	31	7	3	1.78	41.9	22.8	0.13	8.0

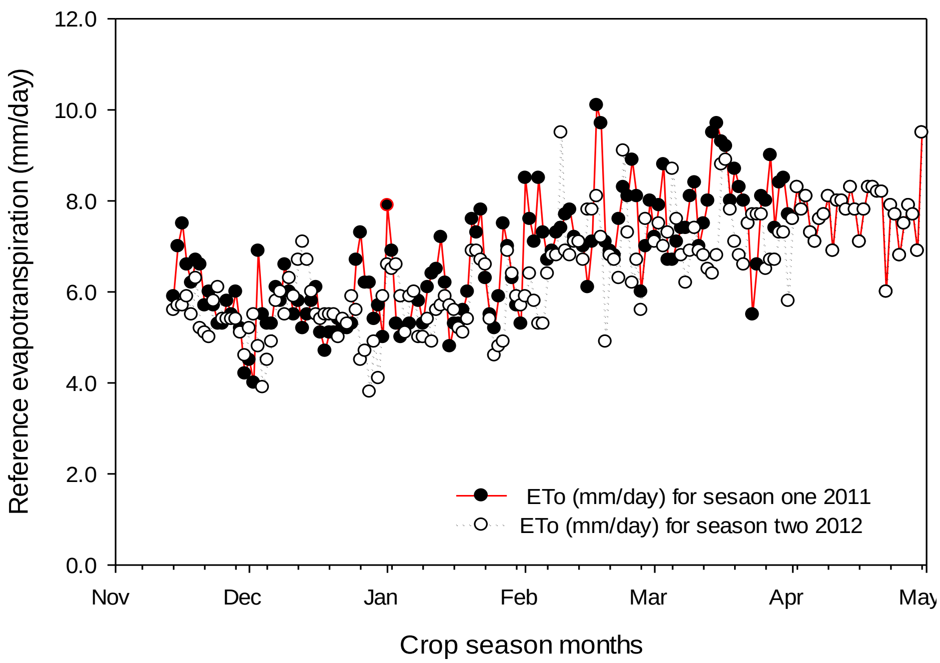

Figure 2. Reference evaporanspiration (ETo) mm/day for two growing seasons.

(cm), number of seeds per head, weight of full seeds, and final seed yield (kg/ha) after harvesting. Harvesting was done on 8 and 15 March during the respective seasons. Data were statistically analyzed using the Statistix 9.0 software and means comparison of data were conducted by Tukey's HSD at 5% probability.

RESULTS AND DISCUSSION

Table 1 displays the weather data for two growing seasons. Regarding the mean average temperature over the two seasons February was the hottest (37.9ºC) followed by November (36.5), and December (35.2) respectively. The warmest March was that of 2012 and the coolest January was that of 2011. The relative humidity generally decreased from November throughout to February. The reference evapotranspiration (ETo) was higher in January and February in 2011 (6.1 and 7.6) during the seed filling and physiological maturity. Analysis of variance for head and stem diameter, plant height, number of full seed, weight of seed per head and total yield as affected by different irrigation frequencies are presented in Table 3. Results showed that the water treatments had a significant effect on the number of seeds per head, weight of full seed and total yield. Seed yield of sunflower decreased (2080 kg/ha) as irrigation interval increased to 20 days after flowering and (2190 kg/ha) after seed filling stages in the first season. While in the second season the seed yield was decreased to 2130 kg/ha and to 2270 kg/ha after flowering and seed filling stages respectively.

The result is in line with the findings of Human et al. (1990), who concluded that water stress in stages of flowering, seed formation and seed filling in sunflower caused the most reduction of seed yield. Beyazgül et al. (2000) reported that the long period of water deficit at the sensitive growth stages caused a significant reduction in seed yield. Faisal et al. (2006) examined the effect of three irrigation intervals (7, 14 and 21 days) on seed and oil yields of a sunflower. They found that sunflower was sensitive to the long irrigation intervals and the reduction in seed and oil yields under prolonged irrigation was associated with a significant reduction in yield components.

Table 3. Effect of irrigation on crop parameters of Sunflower for two growing periods (2011/2012 and 2012/2013).

Irrigation treatment	Plant height (cm)	Head diameter (cm)	Stem diameter (cm)	Number of filled seeds	Weight of 100-seeds (g)	Yield (kg/ha)
2011/2012						
W	153^{a}	20^{b}	2.0^{a}	1060^{a}	5.8^{b}	3130^{a}
F1	153^{a}	19^{c}	2.0^{a}	987b	6.4^{a}	2670^{b}
F2	148^{c}	19^{c}	2.0^{a}	968^{c}	6.0^{a}	$2410b^{c}$
F3	150^{b}	19^{c}	2.1^{a}	851^{f}	5.7^{b}	2080^{h}
S1	152^{ab}	22^{a}	2.2^{a}	1070^{a}	5.5^{c}	2800^{b}
S2	150^{b}	20^{b}	2.1^{a}	868^{d}	5.9^{a}	2350^{c}
S3	150^{b}	19^{b}	2.0^{a}	883^{c}	6.0^{a}	2190^{d}
Mean	151	20	2.1	956	5.9	2400
SE±	2.40	0.82	0.11	102.42	0.38	223
CV%	2.74	2.27	9.06	18.83	11.19	16.10
2012/2013						
W	161^{a}	19^{a}	1.4^{a}	1030^{a}	4.7^{a}	3140^{a}
F1	160^{a}	17^{b}	1.4^{a}	1020^{a}	4.8^{a}	2880^{ab}
F2	160^{a}	16^{c}	1.4^{a}	905^{b}	4.5^{ab}	2510^{b}
F3	160^{a}	15^{d}	1.4^{a}	862^{c}	4.3^{c}	2130^{bc}
S1	161^{a}	17^{b}	1.5^{a}	955^{ab}	4.7^{a}	2840^{ab}
S2	158^{a}	15^{d}	1.3^{b}	920^{ab}	4.6^{b}	2350^{c}
S3	159^{a}	15^{d}	1.2^{b}	880^{c}	4.6^{b}	2270^{bc}
Mean	160	16	1.4	938	4.6	2590
SE±	1.43	1.23	0.09	55.19	0.18	202
CV%	1.54	13.11	12.55	10.12	6.91	10.13

Means followed by the same letters are not significantly different at 5% probability level according to Tukey's HSD.

They found that prolonged irrigation decreased the mean 1000–seed weight. These results are also supported by the findings of Iraj Alahdadi (2011) who reported that increase in the irrigation intervals reduced seed yield, number of seeds per head.

Seed yield (kg/ha)

Seed yield was determined under different irrigation intervals to investigate the effect of different water application during different growth stages on final seed yield. Table 3 demonstrates the results of seed yield and reduction percentage due to different irrigation intervals from three growing seasons. The results revealed that the highest seed yield was obtained from irrigation every week (W) and the lowest seed yield from every 20 days during flowering (F3) and seed filling (S3) stages and the other treatments varied between these two (Figure 3). The results indicated that reduction in seed yield was not significant 5 to 15% when increasing irrigation interval of 10 days after flowering and seed filling stages. Also, the reduction in seed yield was lower 18 to 25% when sunflower crop irrigated every 15 days after flowering and seed filling stages compared with a higher reduction of 34% on the seed yield when irrigation every 20 days after flowering stage was used.

The results stated that sunflower crop was more sensitive to soil water stress (SWS) during the elongation and flowering stages than during seed filling stage. Seed yield significantly improved by optimum irrigation applied after the start of flowering and seed filling stages. Deficit irrigation practices can be an alternate option for improving irrigation schedules and thereby increase crop productivity of restricted water resources under irrigated agriculture. However, deficit irrigation at late seed formation stage slightly increased seed yield in (S2) in comparison with the early flowering stage (Göksoy et al., 2004). Seed yield and number of filled seeds were found to vary significantly. In addition, irrigation deficiency can adversely affect the activities of reproductive organs such as grains and heads because of the high sensitivity of sunflower to water stress during flowering and pollination periods.

Plant height

The results showed that there were no significant differences between treatments in plant height, that is, plant height was not affected when water deficit occurred after flowering and seed filling stages (Table 3). During

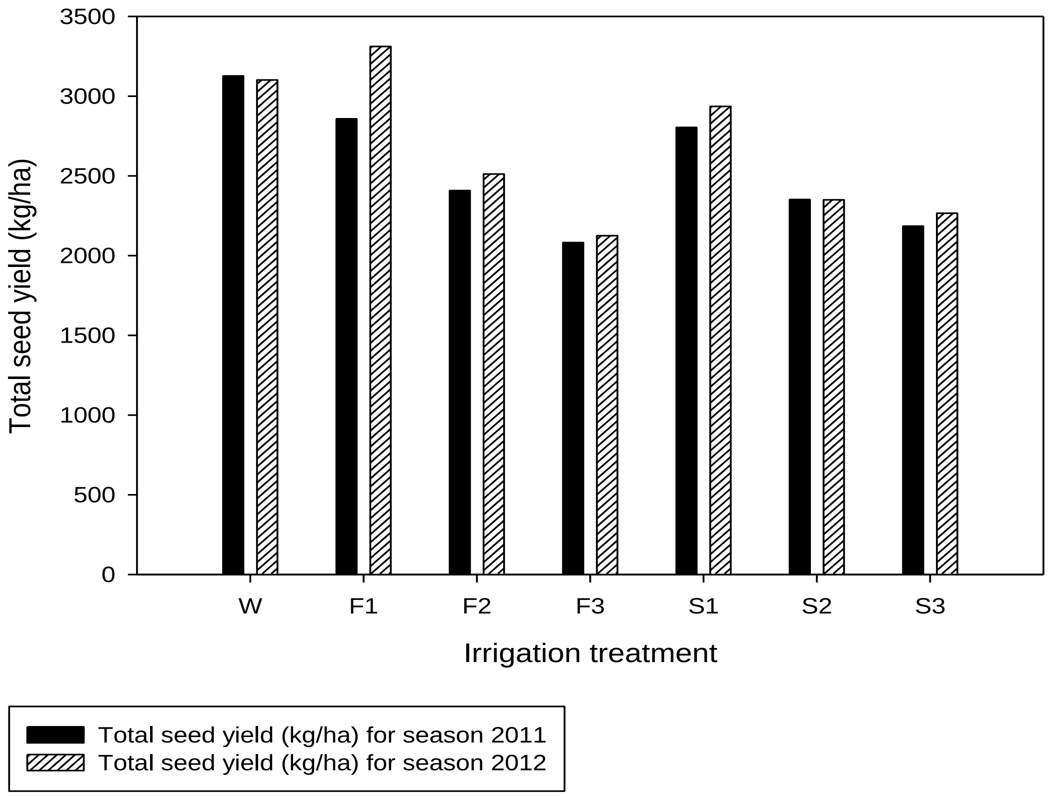

Figure 3. Seed yield of Sunflower under different irrigation intervals for two growing seasons.

the first season the plant height seemed to be shorter (148 to 153 cm) than in the second season (158 to 161 cm), whilst among treatments in the second season it is the same. This contradiction is probably because of differences in environments and material used (bad land preparation and impurity seeds). Thus confirming the findings of (Razi and Assad, 1999) who indicated that the plant height after flowering was not affected by water stress

Head diameter

Head diameter was significantly affected by water deficit during flowering and seed filling stages. Our results are in agreement with the findings of Ghani et al. (2000) who indicated that different irrigation levels had a significant effect on this parameter. Taha et al. (2001) concluded that there was a linear relationship between head diameter and the amount of irrigation levels.

Roshdi et al. (2006) showed that with increasing irrigation interval and applying water stress to sunflower at different crop stages, head diameter and seed yield decreased. Ali and Talukder (2008) stated that deficit irrigation had an effect on head diameter. In this study the smaller head diameter of 15 cm was recorded when the plant irrigated every 20 days after flowering and seed filling stages. While the largest head diameter of 19 and 20 cm was recorded under full irrigation treatment of weekly and 10 days irrigation intervals in two seasons.

Number of seeds per head

Under water deficit conditions, plants do not find enough water to absorb and then the seeds are more or less unfilled. Roshdi et al. (2006) reported that when water stress occurred, particularly during flowering, head diameter decreased and as a result the number of filled grains decreased. In this study there were significant differences between irrigation treatments, the higher number of (1060 and 1030) was observed in weekly irrigation interval (W) and the lower number of (851 and 861) were recorded in irrigation every 20 days (F3) in first and second season respectively. On the other hand, frequent irrigation resulted in the highest number of seeds per head (Table 3). This confirmed the results of Asbagh et al. (2009) who found that the higher seed number per head and seed yield were obtained from full irrigation treatment. Deficit irrigation at flowering stage was observed to be a limiting factor for the number of seeds/head and seed yield. Moreover, seed production was positively correlated to the number of seeds/head. In contrast, seed production increased with increased

Table 4. Oil and protein content (%) as affected by different irrigation intervals for two seasons (2011 and 2012).

Irrigation treatment	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
	Season 2011		Season 2012	
Weekly irrigation (W)	42	14.8	41	13.9
10 days after 50% flowering (F1)	42	13.9	42	13.8
15 days after 50% flowering (F2)	41	13.8	39	14.0
20 days after 50% flowering (F3)	37	14.1	38	13.7
10 days after seed filling stage (S1)	40	14.6	41	14.4
15 days after seed filling stage (S2)	39	14.7	38	13.8
20 days after seed filling stage (S3)	38	14.2	38	14.4

number of irrigations (Rawson and Turner, 1982). The increase in yield was mainly due to increase number of seeds/head and not to seed size. Sunflower showed slightly lesser performance under 15 days intervals compared to other treatments. Moreover, no seed yield was achieved by increasing the irrigation period to physiological maturity.

Oil seed content (%)

The oil percentage is an important evaluation parameter of sunflower quality, which may be affected by deficit irrigation. Sunflower seeds contain a good quality oil (37 to 42%) as well as high amounts of protein (14.8%). Previously, studies reported that the percentage of oil content of sunflower slightly decreased when the crop was exposed to water stress at flowering stage (Hamid and Abolfazl, 2013). Significantly, there were no differences observed in oil content among different irrigation treatments (Table 4).

The higher oil percentage (42%) was recorded when applied full irrigation during the whole growing season, and the lower percentage of (37%) when plants subjected to water stress at flowering stage, while water stress occurred after seed filling stage had no significant effect on it (Bashir and Mohamed, (2014). Oil content increased with increasing the amount of irrigation. Results from two seasons clearly showed that there were no significant differences in protein content among all treatments. The results showed that, water stress significantly ($P \leq 0.05$) decreased seed yield, yield components and seed oil content, but increased the seed protein content in all the irrigation treatments. However, the irrigation water stress did not have an effect in protein content.

Water productivity (kg/m^3)

There are many definitions for the term of water productivity (WP), WP may express a physical ratio between yield and water use, or between the value of the product and water use (Kijne et al., 2003; Palanisami et al., 2009). Therefore, it is important to define the concept used, in this paper water productivity (WP) is defined as the ratio between actual yield and the water applied. Table 5 demonstrates the water productivity for sunflower under different irrigation treatments. Water productivity was higher under weekly irrigation (0.26 kg/m^3) in the first season (Ali and Talukder, 2008), but in the second season it was higher (0.34 kg/m^3) than in the first season, also 10 days before flowering and seed filling stages. WP was lower when sunflower received irrigation at 20 days intervals after flowering (0.21 to 0.26 kg/m^3) and seed filling (0.21 to 0.27 kg/m^3) stages in the first and second season, respectively. The reduction was 20% and 25% in the first and second season respectively. Therefore, each additional m^3 of water yielded 0.26 kg of seed, whereas the output of other irrigation applications was much lower for each additional unit of water, 0.23 and 0.21 kg/m^3 of 15 and 20 days interval after flowering and seed filling stages respectively in the first season. Moreover, lower water productivity of 0.26 and 0.27 kg/m^3 were obtained from irrigation intervals of 20 days after flowering and seed filling stages in the second season respectively. Table 5 shows that higher and lower amount of water applied were recorded under seven days irrigation interval and 20 days irrigation interval after 50% flowering.

Conclusion

The highest seed yield was obtained from a weekly irrigation interval. According to this study, it is concluded that there was no significant effect of irrigation stress on plant height, stem diameter and 100-seed weight after flowering and seed filling stages. The results concluded that the most sensitive growth stages to water deficit were flowering and seed filling stages. The results revealed that the irrigation water productivity for sunflower was low under different irrigation intervals under Gezira conditions. The results also showed that water productivity was low under Gezira condition due to

Table 5. Water productivity (WP) of different irrigation treatments for season.

Irrigation treatment	Yield (kg/ha)	Irrigation supplied (m^3/ha)	WP kg/m^3
Season 2011/2012			
Every week	3130	12000	0.26
10 days after 50% flowering	2670	11200	0.24
15 days after 50% flowering	2410	10400	0.23
20 days after 50% flowering	2080	10400	0.21
10 days after seed filling stage	2800	10600	0.26
15 days after seed filling stage	2350	10900	0.22
20 days after seed filling stage	2190	10300	0.21
Season 2012/2013			
Every week	3140	9350	0.34
10 days after 50% flowering	2880	9400	0.31
15 days after 50% flowering	2510	8600	0.29
20 days after 50% flowering	2130	8240	0.26
10 days after seed filling stage	2840	9480	0.30
15 days after seed filling stage	2350	8540	0.28
20 days after seed filling stage	2270	8470	0.27

inefficiency in water use, weak performance of irrigation system and mismanagement.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effect of different sources of lipids in diet on the qualitative characteristics of *Longissimus thoracis* muscle of cattle finished in feedlots

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The objective of this study was to determine the effect of the dietary inclusion of lipid-based diets (whole cottonseed and protected fat) on the pH, meat color and fat, tenderness and cooking yield in *Longissimus thoracis* muscle of cattle feedlot. Were used 39 Nellore cattle uncastrated with average initial body weight of 494.1 ± 10.1 kg and 36 months of age were housed for 63 days in pens with thirteen animals each. A completely randomized design with three treatments and thirteen replications was used. The treatments evaluated were: Feed with 2.50% whole cottonseed (control diet); feed with 11.50% whole cottonseed; and feed with 3.13% whole cottonseed added of protected lipid (PL), all on a dry matter basis. No differences were found for pH 24 h post mortem, meat color and fat, tenderness or cooking yield. The values of shear force of meat the animals presented differences (P <0.05), and the animals fed with 11.50% of cottonseed had greater value than those fed 2.50% on the diet, in relation to dry matter. The study came to the conclusion that the protected lipid does not influence the qualitative characteristics of meat and the amount of 11.50% of cottonseed in the cattle diet does not contribute to the improvement of texture and tenderness of the meat.

Key words: Color, cooking yield, shear force, whole cottonseed.

INTRODUCTION

The livestock beef cattle production is important activities of the agribusiness in Brazil, being one of the largest exporters of beef in the world. The farms seek to produce efficiently and with this new demand for quality meat. The

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consumers search products competitiveness and require the availability of low cost and better quality (Ruviaro et al., 2014).

To Brazil, maintaining this condition each year has expanded the studies on nutrition of ruminants on the performance and carcass characteristics and meat. One of the main problems encountered in the feeding of cattle confined is related to metabolic disorders caused by the excess of high carbohydrates such as starch fermentation in rumen. The increase in the supply of lipid can be an alternative to reduce the inclusion of starch, maintaining the same energy level of the diet. Thus, the cottonseed has long been used in the feeding of ruminants with this purpose.

However, excess dietary lipid can cause negative effect on fiber digestion in the rumen and influence on quality of meat (Rogério et al., 2003). One way to avoid this negative effect of lipid on the microorganism that digests fiber in the rumen is the supply of protected lipid in the rumen biohydrogenation (Aferri et al., 2005). However, in the literature there are few results the use of protected lipid on the characteristics of quality of meat.

The objective of evaluation the influence of whole cottonseed and of protected lipid on pH, color of meat and fat, the tenderness and cooking the *Longissimus thoracis* muscle of cattle finished in feedlots.

MATERIALS AND METHODS

Study location

The study was carried out in the Chapéu de Couro Farm, located in the city of Aguaí/SP, Brazil, at 22°04′00″ South, 47°09′03″ West, average altitude of 615 m above sea level. The region is characterized by a hot and humid seasons from October to March, followed by a cold and dry season from May to September. The climate of the region is Cwa in the Köppen classification (mesothermal, with hot and humid summers and dry winters).

Animal management and treatment

A group of 39 uncastrated, Nellore animals raised in *Brachiaria humidicola* pastures was used in the study. Mean age of the animals was 36 months and initial mean live weight was 494.1 ± 10.1. Animals were identified and dewormed with Ivermectin 1% before the beginning of the trial. Then, animals were randomly assigned to one of three treatments, based on dry matter: feed with 2.50% CS (control diet), feed with 11.50% CS, and feed with 3.13%% CS added of 1.77% protected lipid (PL). Animals were confined for 63 days (experimental period) in collective pens of 247 m^2 (19 m^2 per animal). The confinement facility was made up of three pens with sand floors, with 13 animals per pen. Feeders and drinkers in these pens were provided with roofs and animals had free access to them. Feeders were made of concrete, and the length available per animal was 0.70 m. A 10-day period was used for the adaptation to the diet and management prior experimental period, in which concentrate was gradually added to the feed, until a 50:50 forage:concentrate ratio was reached. The experimental diets were formulated in the CNCPS software 4.0 (CNCPS, 2000) for uncastrated finishing cattle to provide weight gains of 1.4 kg/animal/day. Forage:concentrate ratio was 50:50 on a dry matter basis. All the concentrate ingredients and forage were weighted in order to prepare the experimental diets, using electronic weighing scale kg. Sugar cane chopped was used as forage, and concentrate was made up of urea, cracked corn kernels, citrus pulp, cotton meal, CS and/or PL. The PL used in this study was made from soybean vegetable oil and had fatty acid calcium salts in its composition. Animals were fed twice a day at 8 am and 4 pm, in a total mix diet, with about 5% leftovers that were weighted in the morning for diet adjustment. Nutritional composition of the diets is shown in Table 1.

Procedures for data collection

After thawing, composite samples of a 21-day period were obtained. Samples of feed and forage were weighted and pre-dried at 60°C for 72 h. Then, they were weighted again in a mill with 1-mm sieves, and stored in plastic bags. Samples of the experimental diets were sugar cane and concentrate which were collected every seven days, placed in plastic bags and stored in at -4°C for subsequent measurements.

The samples were analyzed for Proximate Analysis according to AOAC (1990) and NDFom and ADFom (excluding ash) according to procedures of Van Soest et al., 1991), and lignin by the sulphuric acid method Lignin (sa), after a sequential neutral-acid detergent extraction (Van Soest et al., 1991). In the NDF analyses, thermostable α-amylase was used without sodium sulfite (Mertens, 2002). Non-fiber carbohydrates (NFC) in the ingredients of the diets were determined by the following equation, according to Sniffen et al. (1992), NFC = 100 - (%NDFcp + %CP + %EE + %MM). Due to the presence of urea in the diets, NFC in them were calculated as indicated by Hall (2000): NFC = 100 - [(%CP - %CP from urea + %urea) + %NDFcp + %EE + %Ash]. Estimated metabolizable energy (ME) in Mcal/kg of DM was determined according to the NRC (1996) recommendations, considering that 1 kg of total digestible nutrients (TDN) contains 4.409 Mcal of digestible energy (DE), using 0.82 as the conversion factor to transform DE in ME. Analyses of the feed samples were carried out in the Food Analysis Laboratory at the Animal Nutrition and Improvement Department of Faculdade de Medicina Veterinária e Zootecnia at Universidade Estadual Paulista, Botucatu campus. Results of these analyses are shown in Tables 2 and 3.

Slaughter procedures and sample preparations

After 63 days of the study, animals were weighted for the last time after a 14-h solid food fasting. Mean final live weight was 577.01 kg ± 11.34. Soon after being weighted, animals were taken to a slaughterhouse (FRIGONOBRE, in the city of Torrinha, state of São Paulo), 166 km from the study site, in solid food fasting until the moment they were slaughtered. Animals were slaughtered according to the regular flow of the industry.

After slaughter, carcasses were identified and divided into two halves that were kept in a cold chamber for 24 h at 2°C. Using pH meter was determined *post-mortem* pH in *Longissimus thoracis* muscle between the 12^{th} and 13^{th} rib of the left half carcass. After, part of each animal was removed, and divided in three samples (steaks). Steaks were 2.5 cm thick and were identified and stored individually in plastic bags under vacuum. Samples were frozen in a freezer at -18°C at Universidade Estadual Paulista, Faculdade de Ciências Agronômicas, Botucatu campus, at the Animal Products Technology Laboratory.

Chemical analysis of the meat and fat color

Samples of *Longissimus thoracis* muscle of each animal were

Table 1. Chemical composition of the experimental diets on a dry matter basis.

Ingredients (%)	Dietary treatments		
	2.50% CS (control)	11.50% CS	3.13% CS + PL
Sugar cane	50.00	50.00	50.00
Cracked corn	14.64	13.07	13.12
Citrus pulp	21.61	17.81	20.61
Cottonseed	2.50	11.50	3.13
Cottonseed meal	9.30	5.78	9.42
Urea	0.83	0.83	0.83
Protected fat	-	-	1.77
Mineral mix[1]	0.83	0.83	0.83
Potassium chloride	0.28	0.17	0.28
Ionophores	0.01	0.01	0.01

[1]Composition /kg: P = 60g; Ca = 180g; Mg = 5 g; S = 17 g; Na = 135 g; Cu = 650 mg; Mn = 500 mg; Z n= 2400 mg; I= 48 mg; Co = 38 mg; Se = 12 mg; CS = cottonseed; PL = protected lipid.

Table 2. Mean chemical composition of ingredients used in the experimental diets as percentage dry matter.

Ingredients	DM (%)	% dry matter						
		CP	EE	NFC	NDFmo	ADFmo	LIG	MM
Sugar cane	30.27	2.82	2.93	29.06	62.43	39.56	6.85	2.76
Cracked corn	87.02	8.73	4.46	71.46	14.42	5.32	2.75	0.93
Citrus pulp	87.94	5.87	3.5	64.78	21.38	16.75	7.52	4.47
Cottonseed	91.00	19.67	20.83	1.36	54.65	45.44	17.03	3.49
Cottonseed meal	87.24	46.08	1.94	0.12	45.66	28.32	9.91	6.20
Protected lipid	95.47	-	85.21	-	-	-	-	14.79
Urea	99.51	287.84	-	-	-	-	-	-

NFC according to Sniffen et al. (1992).

Table 3. Mean chemical composition of experimental diets used in different levels of cotton seed.

Items	Diets		
	2.50% CS (control)	11.50% CS	3.13% CS + PL
DM (%)	58.09	58.50	58.26
CP (% of dry matter)	11.11	10.90	11.11
EE (% of dry matter)	3.57	5.18	5.11
NFC (% of dry matter)	38.61	35.03	36.88
NDFom (% of dry matter)	43.56	45.83	43.52
MM (% of dry matter)	3.15	3.06	3.38
TDN[1]	67.55	68.16	68.99
ME[2]	2.44	2.46	2.49

NFC according to Hall (2000); [1]Estimated in the feed composition according to the CQBAL 3.0 (2012) and the NRC (2001)[2] ME = estimated metabolizable energy, in Mcal/kg of DM, according to the NRC (1996).

thawed in refrigerator, then removed from the packaging and exposed to the air for 30 min to allow oxygenation surface. The color of the meat was determined by the Minolta colorimeter CR-410 and the color of the subcutaneous fat, using the optional Milnolta CR-400 second Honikel (1998). The parameters evaluated were L*, a* and b* the CIELab system, where L* is brightness, a* represents intensity of red and b* intensity of yellow.

Cooking yield and shear force (aged beef)

The samples were weighed in the balance semi-analytical and

Table 4. Characteristics aging times of meat and subcutaneous fat color the Nellore cattle fed with different diets.

Characteristics	Diets				
	2.50% CS (control)	11.50% CS	3.13% CS + PL	SE	P-value[1]
Meat					
pH 24 h	5.66	5.54	5.57	0.06	0.34
Shear force (kg)	5.10[b]	6.30[a]	5.83[ab]	18.45	0.02
Cooking yield (%)	83.13	76.57	79.82	10.11	0.14
Brightness L*	38.51	39.83	39.57	4.92	0.19
Intensity the red a*	15.52	15.93	16.36	8.08	0.26
Intensity of yellow b*	3.44	4.33	4.26	28.03	0.09
Fat					
Brightness L*	64.80	65.64	65.59	6.08	0.83
Intensity the red a*	10.88	9.77	10.90	28.72	0.55
Intensity of yellow b*	8.89	8.85	8.97	25.41	0.99

[1]According to Tukey test (P< 0.05); [a, b] Different letters in line indicate significant difference. CS = cottonseed; PL= protected lipid; SE = standard error.

submitted to cooking on a grid until they reach the automatic internal temperature of 71°C, as measured by a digital thermometer in the geometric centre of the sample. The evaluation of proceeds in cooking was made by the difference between the weights of the samples before and after cooking according to the methodology of Honikel (1998). The same samples cooked were refrigerated by 12 h the 4°C, and then cut into cylinders 1.10 Øcm with the support of a drill press avoiding fats and nerves. Shear force was calculated in these samples cut into cylinders through the Brookfield texture CT3 Texture Analyzer 25 k equipped with a set of blade Warner-Bratzler according to the methodology of Savell et al. (2015).

Statistical procedures and model evaluation

A completely random design with 3 treatments and 13 repetitions was used, according to the Yij = μ + Ti + eij model, where: Yij is the value observed in the j^{th} experimental unit (animal) that received the i^{th} treatment; μ is the overall mean; Ti is the fixed effect of the i^{th} treatment; eij is the experimental error related to the experimental unit. Data were analyzed by means of the Generalized Linear Models Procedures (GLM). The averages were adjusted by the method of least squares (Least Squares Means). Statistical analyses were performed using the SAS program (2002), and means were compared using Tukey test at a 5% significance level.

RESULTS

The characteristics the meat and subcutaneous fat the Nellore cattle was shown in Table 4. No differences in pH 24 h after slaughter were observed in the meat of Nellore cattle fed different sources of fat (Table 4), and mean value for this variable was 5.59. Difference was not observed (P > 0.05) to cooking yield of muscle *Longissimus thoracis* the Nellore cattle fed lipid sources. However, for the shear force differences (P < 0.05) were founded. For diet control the lowest value found 5.10 (kg) while for the treatment with 11.50% CS the great value found was 6.30 (kg). It may be observed in Table 4, for Brightness L*, intensity the red a*, intensity of yellow b* that there were no differences (P>0.05) between the treatments for characteristics the meat or fat.

DISCUSSION

After 24 h analysis of pH *post-mortem* of the Nellore cattle the mean value for this variable was 5.59. In the same way as, findings similar to those of the present study were reported by Aferri et al. (2005), who studied the use of additional fat in the diets of confined crossbred beef steers. These authors did not find any differences between the diets containing or not the lipid source, either. They reported a mean pH value of 5.56 after 24 h of slaughter.

As uncastrated animals are more easily stressed, according to Luchiari Filho (2000), inadequate management during management, transportation, and slaughter may lead to dark, firm and dry carcasses. This condition is always observed when pH is greater than 6.0. In Brazil, slaughterhouse export only meat with pH is lowers than 5.8, determined directly on the *Longissimus thoracis* muscle 24 hours after slaughter (Fernandes et al., 2008). Mean pH 24 h after slaughter in the present study (Table 4) suggests that stress was not too high before slaughter, as muscle acidification was inside the expected range.

For shear force different the results observed in this study, Costa et al. (2013) found no differences in shear force on *Longissimus thoracis thoracis* muscle of cattle fed growing Nellore whole cottonseed levels in the diet, as well as Aferri et al. (2005) and Andrade et al. (2014) also did not observe differences by including whole cottonseed or rumen protected lipid in diet. Second, Labrune et al. (2008) as worked with a lipid-rich diet and not observed change in shear force on tenderness or succulence of meat from steers. High shear force values mean greater texture of meat that indicates less tenderness. The texture of the meat can be influenced by age, weight to the slaughter of animals. For cattle breed Nellore *Bos taurus indicus* more high value of shear force (Shackelford et al., 1994).

For cooking yield of cattle fed lipid sources showed no differences. Similar results were founded for Aferri et al. (2005), Costa et al. (2013) and Andrade et al. (2014) did not observe differences to the loss by cooking to feed cattle with whole cottonseed or protected lipid. When cooking meat compounds losses include free amino acids, peptides, reducing sugars, vitamins and lipids (Watanabe et al., 2015).

In studies with brightness the meat second Suman et al. (2014) to improve beef color and attempted to logically explain the fundamental mechanisms involved. However, the surface color and its stability are critical traits leading the marketability of fresh beef when sold, while internal cooked color is utilized as an indicator for doneness at the point of consumption. For brightness L*, intensity the red a*, intensity of yellow b* the muscle initial red color intensity increased whereas both mitochondrial oxygen consumption and color stability decreased. The decrease in mitochondrial oxygen consumption associated with longer aging times will increase initial color intensity (Mancini and Ramanathan, 2014). Similar result founded in study case Costa et al. (2013) no differences in this characteristics is this feature evaluated for cattle fed with increasing levels of whole cottonseed in the diet. Same results were observed for Oliveira et al. (2012) with meat color composition evaluated from Nellore cattle fed fat protected lipids and did not view an alteration in these parameters, due to the consistency in the breed, age and meat pH of the animals.

Conclusion

The supply of protected lipid in the diet of cattle does not influence the quality of the meat. The whole cottonseed does not contribute to the improvement of texture and tenderness of the meat.

Conflict of Interest

The authors declare that they have no conflict of interest related to this study.

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Full Length Research Paper

Export quality surgical cotton from NE India

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Pesticide free premium quality surgical cotton with a competitive price advantage is available in the north eastern states dominating with Meghalaya, Assam, Mizoram, Tripura, in *Jhum* cultivation (*Gossypium arboreum cernum)* and north coastal Andhra Pradesh states, India (*G. arboreum indicum*) which are the natural home. *G. arboreum Cvars* LD 230 and RG-8 will be useful to grow commercially in north eastern India under slash and burn system. In north coastal Andhra Pradesh ground nut/ green gram mixed cropping or sequential cropping with chilles with *G. arboreum indicum* requires adequate manuring (sheep penning, FYM) and topdressing of N: K_2O fertilizers 29:38 kg ha^{-1} besides sheep pennings as topdressing with September rains for both seed and Ratoon crop. Grey mildew is a serious problem in ratooning which needs protective spray of Copper fungicides with September rains. Surgical cotton processing centres can encourage commercial production under contract farming in north eastern India and north coastal Andhra Pradesh which can give a profitable returns of US$ 1000 ha^{-1}.

Key words: Absorbent cotton, Assam *Comilla* cotton, Bengal *desi* cotton, *Gossypium arboreum cernum, Gossypium arboreum indicum*, micronaire, pesticide free, premium quality, slash and burn system, surgical cotton.

INTRODUCTION

Increase in the corporate health care facilities internationally created high demand for pesticide residue free surgical cotton (MSME, 2010; Deshpande, 2011; Jayashree, 2013). Surgical cotton Indian export houses were continuously exporting to European union and China (Anon, 2008). However, they were recently facing shortage of raw materials (CCI, 2012). Bt hybrid cotton invasion was invisible on indigenous cottons in north eastern states and north coastal Andhra Pradesh. Absence of minimum support prices (MSP)/Bt trait and higher ginning out turn in *Gossypium arboreum cernum* cottons grown without pesticides (Guillaume and Yan, 2012), which were in favour of entrepreneurs who want to export EU countries where GMOs are not desirable. De-waxing and carboxilation are needed to get desirable absorbancy of 10 s absorbency and sinking time with water holding capacity > 23 g /g cotton (Mokate et al., 2011; MSME, 2010). ICAR-CIRCOT, Mumbai, India

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developed a chemical free surgical cotton protocol (Gayal et al., 2012).

Assam *Comilla* (7-8 micronaire) / *Bengal desi* (6.8 to 7.2 micronaire) cottons are only exported by leading international brands however, uses high micronaire, very coarse for surgical cotton production due to very few *neps* formed during processing (Cotton Inc, 2012). *Assam Comilla* cotton is traded much below the Minimum support price mainly because of absence of procurement centres of cotton by Cotton Corporation of India in north-eastern states (CCI, 2015). *Bengal desi* (*G. arboreum cernum*) cotton having big bolls produced in mixed cropping situations under pesticide free environment in north east dominating with Meghalaya, Assam, Mizoram and Tripura, in *Jhum* cultivation is unaffected by Bt hybrid cotton invasion. Now it is economical to procure and gin from north east and transport at lower price to destination by rail or shipping from Chittagong port in neighbouring Bangladesh. As the Govt of India policy to act east and spend 10% of its budget, Assam *Comilla* cotton cultivation can be encouraged with incentives which can lead to better employment generation and increase in farmers income.

Similarly, *Punasa* cotton (*G. arboreum indicum*) from north coastal Andhra Pradesh state, India, is also suitably available for export quality surgical cotton. However, commercial exploitation of these land races outside their home of production is subjected to the laws of the recently created National Biodiversity Authority of India (NBDAI). A possible way out is to procure cotton lint from the natural home of their production, ginning and crushing the seeds for oil onsite through one step by middle men which can reduce transportation cost by 65%. On farm trials were conducted by the authors under ICAR-world Bank funded National Agriculture Technology Project, Rainfed cotton Production System (RCPS-9) titled '*Development and evaluation of Technologies for Indigenous cottons''* in North east region. Agro economical study was conducted on *G. arboreum* cotton production sites which were extrapolated to current US $ prices for benefit of farmers, policy makers and young entrepreneurs to identify the optimum surgical cotton varieties, location and prices.

Experimental site character

G. arboreum cotton was commercially grown (2000-2004) on or before large scale expansion of Bt hybrid cotton were selected for this study.

Adilabad (AP), India

Experiments were conducted in *Gaorani* cotton tract at Agricultural Research station, Mudhol (18 58° 77 55° E) of Professor Jaishankar Telangana State Agricultural University, in Adilabad district of Telangana state, India. This site had both shallow red soils and medium deep gravelly *vertisols*. Normal annual rainfall of the district was 1045 mm.

Srikakulam (A.P)

On farm trials were also conducted at villages in *Ponduru*, *Amudalavalsa*, Srikakulam (18°-20' and 19°-10' N and 83°-50' and 84°-50' E) district in north coastal Andhra Pradesh of south eastern India with 900 and 150 mm SW and NE monsoon.

Diphu Assam

Onfarm trials were also conducted in *Karbi Anglong* district of Assam state, in north east India. The soils were sandy loams with steep slopes with 765 and 250 mm SW and NE monsoon.

MATERIALS AND METHODS

Seeds were planted at the experimental sites at 0.6 m x 0.30 m plant spacing in Adilabad and broadcasted in green gram on farm trials in *Jhum* cultivation at *Diphu* (Assam), India. *Punasa* cotton is often broadcasted as annual crop in the back yards of weavers along the coast line in red lateritic and coastal sandy loam soils without any fertilizers and manures. *Hill* / red cotton however, dibbled in groundnut / green gram mixed cropping at 1x1 m a part. Hill cotton is often ratooned with a higher yields and earliness besides drought mitigation at Srikakulam. Fertilizer dose of 60:30:30 kg ha^{-1} N: P_2O_5: K_2O were applied only at Adilabad. Topdressing of N: K_2O fertilizers 29:38 kg ha^{-1} with September rains after harvest of legume mixed crop at Srikakulam. There is no fertilizer/ pesticides supply in north eastern India, the crop was grown by default as organic under Jhum (slash and burn) cultivation at Diphu, Assam, India. Crop was harvested at the maturity weighed and calculated per unit area. Need based plant protection measures were followed in Adilabad and Srikakulam sites as per the requirement. Micronaire was analysed by HVI instrument at ICAR- Central Institute for Research on Cotton Technology (CIRCOT) Mumbai, Ginning Training Centre (GTC), Nagpur. Fish jaw combing is a local practice at Srikakulam for cleaning cotton, removing short fibres besides ginning by jerk on a wooden board with ruler and bow for opening cotton before chording.

RESULTS AND DISCUSSION

Ponduru cottons micronaire

They were suitable for surgical cotton in general and *Punasa* cotton in particular for premium quality range (Table 1) does not need any bleaching. Lower cost of production, absence of MSP/ competitive market forces besides cheaper labour availability for production, ginning and cleaning are ideal conditions for surgical cotton industry in north coastal Andhra Pradesh, India. Contract farming for lint supply is good offer for local farmers/ entrepreneurs through *Khadi* and village industries controlled local weaver co operative societies like *Andhra*

Table 1. Micronaire of Ponduru cottons at Srikakulam (A.P).

Cotton land races	Category	Micronaire(μg/inch)
Red cotton	Fish combed	6.7
Red cotton	No fish combed	6.2
Hill cotton	Fish combed	6.4
Hill cotton	No fish combed	6.2
Punasa cotton	Fish combed	6.4
Punasa cotton	No fish combed	6.4

Table 2. Punasa cotton in coastal sandy loam soils.

Variables	Seed cotton yield kg ha^{-1}	Gross returns US \$ ha^{-1}
Punasa cotton seed crop	350	420
Punasa cotton seed crop with biofertilisers	519	623
Punasa cotton top dressed with 28 kg N ha^{-1}	950	1140

Fine khadi Karmika Sangham at Ponduru and *Srikakulam Fine khadi* at Srikakulam is organizing production and processing of these cottons since decades. Seeds after cleaning and ginning is used by local farmers as animal feed which had ready market and nutrients are recycled in local farms as farm yard manure.

Ponduru cotton production systems

Punasa cotton (Table 2) is predominantly cultivated only as pure crop in coastal sandy clay loam soils. This area is controlled by *Srikakulam Fine Khadi* Society located behind court complex with its retail outlets located in Srikakulam town and villages. Limited extent of red cotton is also grown by them under high rainfall area. The farmers economy is maintained with high plant density usually grown as back yard crop in red, sandy loams and black soils for ready to spin into yarn by rural women. *Punasa* cotton is suitable as direct introduction in to surgical cotton cultivation with minimal care. N fertilizers application of 58 kg $ha^{-1}$and advance payments will be more useful under contract farming. These soils also need N K fertilizer application at least as top dressing for reasonable profit of US $ 1000 $ha^{-1}$for *Punasa* seed cotton and red cotton ratoon (Tables 3 and 4).

Red soils

Red and hill cottons are predominantly cultivated as mixed crops and often ratooned to face the competition from mixed ground nut / sesame / green gram and black gram. Absence of basal fertilizer application, inter-cultures operations, rain water conservation harvesting and recycling as supplemental irrigations besides grey mildew control measures are constraints in cotton production. Small boll size (2 g) and large number of bolls (400 $plant^{-1}$) requires frequent pickings by family labour. Animal pennings for 3-4 days and application FYM are only avenues to maintain soil fertility, besides top dressing of 23:58:75 $N:P_2O_5:K_2O$ application after September rains or after harvest of mixed crop is a local practice due to fear of competition. Top dressing urea found to be very effective under poor N supply. Grey mildew damage is very severe after August rains for ratoon cotton besides occasional losses from boll worms. Ratoon crop matures earlier and produces more than seed crop which has to survive in severe summers. Beheading of cotton leaving one feet height was found superior instead of re sprouting the entire plant. Poor plant stand is also a yield constraint some times gaps filled with seeds. Very high expenditure on manual hoeing and hand weedings can pave way for post emergence herbicides reducing cost of production (Tables 5 and 6). Soils were deficient in potassium and responded well to NK topdressing in September after harvest of legume crop.

Medium black soils

Ratooning is producing more than seed crop. Plant stand of ratoon crop is sufficient but difficult to maintain under severe summer in the absence of irrigations. Lower moisture holding capacity of the soils, boll worms damage and grey mildew are limitations which need attention (Table 7).

Sandy loam soils

Ratoon is producing more than seed crop, therefore, wide spread rationing is followed which is leading to more

Table 3. Red cotton in coastal sandy loam soils.

Ampolu village	**Seed cotton yield kg ha^{-1}**	**Gross returns US $ ha^{-1}**
Pure crop no fertilisers	250	300
Pure crop with bio-fertilisers,	386	463
Mixed crop with *ragi* and bio-fertilisers	595	714
Mixed crop with black gram and bio-fertilisers	194	233
Biru singa puram village		
Ratoon crop top dressed with 28 kg N ha^{-1}	**1125**	**1350**
kishtappa peta village		
Red cotton seed crop	286	343

Table 4. INM in groundnut mixed crop in red soils at Nimmalavalasa, Sirkakulam Dist (A.P).

Variables	**Fertilizers Kg ha^{-1} N: P_2O_5 :K_2O**			**Organic manures tonnes ha^{-1}**	**Sheep pennings days/ Year $^{-1}$**	**Seed cotton Yield Kg ha^{-1}**	**Gross returns US $ ha^{-1}**
Red cotton	**12**	**29**	**50**	**15**	**6**	**1000**	**1200**
Hill cotton	40	29	0	11	3	600	720

Table 5. Onfarm trials in red soils at Nimmalavalasa, Sirkakulam Dist (A.P).

Treatments	**SCY kg ha^{-1}**	**Mixed crop Ground nut yield kg ha^{-1}**	**Gross returns US $ ha^{-1}**
Red cotton seed crop 40 kg N ha^{-1}	375	538	1363
Red cotton seed crop with no fertilizer	334	501	1236
Hill cotton ratoon crop 23:58:75 N:P_2O_5:K_2O	334	358	1093
Hill cotton seed crop with no fertiliser	250	501	1051
Hill cotton seed crop with 40:29:0 N:P_2O_5:K_2O	600		720
Hill cotton Ratoon crop with no fertiliser	167	250	617

Table 6. Red and Hill cottons in shallow black soils of Madhupam, Srikakulam.

Treatment	**Seed cotton yield kg ha^{-1}**	**Gross returns US $ ha^{-1}**
Red cotton ratoon crop without fertilizers	217	260
Red cotton ratoon crop -chillies on residual fertility	375	450
Hill cotton seed crop with biofertilisers and 28 kg N kg ha^{-1}	217	260
Hill cotton ratoon crop with 58 kg N 75 kg K_2O kg ha^{-1}	592	710

Table 7. Hill cotton in Sandy loam soils Narsapuram, Ponduru, Srikakulam Dist (A.P).

Treatment	**Seed cotton yield kg ha^{-1}**	**Green gram kg ha^{-1}**	**Horse gram kg ha^{-1}**	**Gross returns US $ ha^{-1}**
Hill cotton with green gram and biofertilisers.	63	56	34	142
Hill cotton with 5 tonnes FYM and 28 kg N ha^{-1} as basal dose with biofertilisers	750	1000	250	**1938**

Table 8. Kishtappa peta village, Ponduru (Srikakulam Dist) A.P.

Variables	Fertilizers applied Kg ha^{-1}			Organic manures	Sheep pennings	Seed cotton Yield Kg ha^{-1}	Gross returns US $ ha^{-1}
Crop	N	P	K	tonnes ha^{-1}	Days/ Year $^{-1}$		
Hill cotton	50	29	0	1.5	3	700	840

Table 9. *G. arboreum* cottons yield as mixed crop in green gram at Diphu, Assam (India).

Variables	Seed cotton yield kg ha^{-1}	Green gram kg ha^{-1}	Gross returns realized ha^{-1} US $			Micronaire (µg/inch)
			Farmer	Entrepreneur using local gin	Entrepreneur using factory gin	
LD 230	904	750	1647	134	167	
RG-8	823	750	1550	122	152	
Karbi local	**639**	750	1329	95	118	7.8
MDL 1875	578	750	1256	86	107	
AKH-5	560	750	1235	83	104	
AKA 8401	560	750	1235	83	104	
Lohit	540	750	1211	80	100	
Y1	504	750	1167	75	93	
K10	467	750	1123	69	86	

grey mildew and pink boll worm problem. Lower moisture holding capacity of the sandy loam soils is a severe limitation where mixed cropping is followed (Table 8). Hill cotton needs adequate manuring and topdressing of N, K fertilizers to get required economical yield and profitability (Table 8).

Assam *Comilla* cottons are 3rd in order of profit for both farmers and entrepreneurs under mixed farming situations of *Jhum* cultivation along with green gram with no external inputs being low yielders they were next only to LD 230 and RG-8 (Table 9). Premium quality pricing if paid can be expanded and second quality by LD 230 and RG-8 if NBDAI restricts its commercial cultivation. Although improvement of these cottons were initiated by breeders but maintaining higher boll weight and coarseness is difficult except under hybrid conditions as observed by at ARS, Mudhol (Laxman, 2009) which was notified as MDLABB-1 and CICR, Nagpur hit the head lines and attracted attention of cotton world on the cotton productivity (Anonymous, 2013). Pure line selections were made within local ecotypes at RARS, *Diphu*, *Karbi Anglong* district (Assam) and were tested in NATP project RCPS-9 but seeds could not be maintained by respective breeders.

Gaorani cotton tract is once the home of *desi* cottons covering two states of Telangana and Maharashtra states. This tract is now gets severe competition with Bt hybrid cottons although they may not give 1000 US $ but that is expected for a fairly good standard of living for farmers. This target can be achieved by premium quality LD 491 followed by Lohit and G-27. After this MDL 1875, K-10, LD-230 AKA-7 and AKA 8401 can be profitable in second quality for national requirement (Table 10). However, in the absence weighted premium for Bt trait and ginning out turn they cannot be competitive with Bt hybrid cotton.

Vidarbha and *Malwa* regions of Central India was once commercial production centres for *desi* cottons were totally replaced by Bt hybrid cotton (Table 11) due to boll worm susceptibility except pockets in Jalgaon of *Khandesh* region, *Melghat* of Amraoti and Murtizapur of Akola (MS) in *Vidarbha* region. Y-1, JLA-794, Jawahar Tapti, AKA-5 were used by local surgical industry for surgical cotton production. MPKV, Rahuri recently released *Phule Dhanwantary*, which produced higher seed cotton yield 1418 kg ha^{-1} over Y-1 1279 kg ha^{-1} and JLA-794 1292 kg ha^{-1}. It had absorbency of 1.9 s and sinking time 2.0 s. with water holding capacity 26.7 g /g of cotton as compared to Y-1 6.5 and 8.5 s and 25.0 g /g of cotton, respectively used for surgical cotton production for local requirement. G-27, RG-8, LD-491, Lohit, LD-230 and *Karbi* cotton were profitable with weighted premium to local farmers in medium deep soils.

Conclusion

Premium quality surgical cotton with a competitive price advantage is in the natural home of *G. arboreum cernum/ indicum* cottons. Processing centres can encourage LD 230 and RG-8 in north east India under *jhum* cultivation, adequate manuring and NK fertilizers are essential at

Table 10. Micronaire of *G. arboreum* cotton varieties at ARS, Mudhol, Adilabad (A.P).

Varieties	Yield kg ha^{-1}	Gross returns realized US $ ha^{-1}	Micronaire (µg/inch
G-27	1237	1031	6.1
Lohit	1119	933	6.3
MDL-1875	1022	852	5.5
K-10	1015	846	5.5
LD-230	991	826	5.5
AKA-5	982	818	5.5
LD-491	954	795	6.8
Hill cotton	850	708	6.2
RG-8	835	696	6.9
Red cotton	800	667	6.2
Punasa cotton	600	500	6.4
CD±5%	287	239	0.6

Table 11. Agronomical performance *G arboreum* cottons in medium deep black soils, Nagpur (M.S).

Year	Yield kg ha^{-1}	Gross returns US $$ha^{-1}$	Micro naire (µg/inch)
G-27	1162	968	6.1
Karbi	1139	949	5.1
Lohit	1056	880	5.8
LD-230	1013	844	5.5
RG-8	973	811	6.1
LD-491	953	794	6
CD±5%	346	288	0.5

least as topdressing to realize economic yield levels.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Isolation and inoculation of diazotrophic bacteria in rice (*Oryza sativa* L.) grown in Vitoria da Conquista - BA

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With the aim of isolating and inoculating diazotrophics bacteria, which is an efficient biological nitrogen fixation (BNF) in rice in Vitoria da Conquista - Ba, the present study was carried out in three steps. In the experiment of inoculation of diazotrophics bacteria, BRS Tropical and BRS MG Curinga, inoculation with the strain of bacterium ZAE 94, absence of inoculation and four doses of N (0, 20, 60 and 100 kg ha^{-1}) were used. The control plants were used for the implementation of the isolation of bacteria efficient as the BNF. Final experiment was carried out with the three isolated strain, the ZAE 94, the absence of inoculation and the interaction with doses of N. Inoculation with strains of diazotrophic bacteria, guaranteed an increase in agronomic variables studied with positive effects on production and grain up to 208.5%.

Key words: Biological nitrogen fixation (BNF), *Herbaspirillum seropedicae*, grain production.

INTRODUCTION

Oryza sativa L. rice is a plant that belongs to the family of *Poaceae*, being the third-largest cereal crop in the world, only exceeded by corn and wheat. Rice is a cereal of basic human diet, representing approximately 20% of the world energy intake and 15% of protein intake (Kennedy and Burlingame, 2003). Among the various ways of increasing plant production, the supply of fertilizers stands out, while nitrogen being the most important element for obtaining high productivity, because it acts as the synthesis of proteins and enzymes that guarantee the life of the plant. Nitrogen is an element that is easily lost through leaching, volatilization and denitrification in soil-plant system (Fageria and Baligar, 2005), irrational use of nitrogenous fertilizer burden the costs of production and

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can cause negative effects to the environment, such as contamination of water courses and increasing the concentration of greenhouse gases. Alternative sources of nitrogen supply to plants, such as the biological nitrogen fixation (BNF), can supplement or even replace the use of nitrogenous fertilizers in agricultural processes. The BNF is one of the most important processes known in nature, being performed by prokaryotic organisms. Diazotrophic bacteria are able to reduce the N_2 atmosphere making it understandable to the plants (Reis et al., 2006).

The actuation of diazotrophic bacteria regarding the biological fixation of nitrogen was verified initially between the legume plants, a better result is achieved in the soybean crop, where the BNF can provide up to 94% of the N, required by most productive cultivars (Hungria et al., 2006). In non-leguminous plants, the process of BNF is not as efficient as in soybean crop, numerous experiments have demonstrated that plants of the family *Poaceae* present significant potential, responding with an increase in production when inoculated with diazotrophic bacteria (Baldani et al., 2002; Guimarães et al., 2003; Campos et al., 2003; Guimarães et al., 2010). Bacteria capable of fixing atmospheric nitrogen, such as the genera *Herbaspirillum*, *Burkholderia* and *Azospirillum* have been isolated from various grasses in several experiments (Perin et al., 2006; Rodrigues et al., 2006; Reis Junior et al., 2004).

The inoculation with N-fixing diazotrophic bacteria is a viable alternative for the producer, with significant increases in yield and reduction in the use of nitrogen fertilizers with lower costs. The isolation of diazotrophic bacteria native of Bahia and their inoculation in rice plants may have bigger effects on the BNF, than bacteria from other regions of Brazil, as these may have greater adaptability to the conditions of the state's productive regions.

This study aimed to isolate and inoculate diazotrophic bacteria efficient as the BNF in rice (*Oryza sativa* L.) cultivar BRS Tropical cultivated in Vitoria da Conquista, and with potential to be use in the Southwest region of Bahia.

MATERIALS AND METHODS

Inoculation of diazotrophic bacteria experiment

The experiment was conducted in a greenhouse at the Campus of the State University of Southwest Bahia (UESB), in Vitoria da Conquista, located in the southwest region of the state, at 14°51' South latitude, 40°50' west longitude, at height of 928 m.

The first 20 cm from a Yellow Latosol (Oxisol), flat terrain, with medium texture, coming from the experimental field UESB were used, with the following chemical characteristics: pH 5.4, 22-3 g dm^{-3} of organic matter, 2.0 mg dm^{-3} of phosphorus and 0.1 $cmol_c$ dm^{-3} of potassium. Pots were used with 9kg capacity. The correction of soil fertility was performed according to the recommendations of the use of lime and fertilizers in Minas Gerais (Ribeiro et al., 1999) for upland rice, higher than the recommendation of the correction of soil fertility according to the Manual of Fertilization and Liming for the state of Bahia.

The experimental design was entirely randomized and treatments arranged in a factorial design (4 x 2), where the first factor had doses applied as urea (0, 20, 60 and 100 kg of N ha^{-1}) and the second factor had the presence or absence of inoculant. Eight treatments were performed with six replicates for Tropical BRS and BRS genotypes, with four plants per pot.

The inoculation was done on the day of sowing. The inoculum was from Embrapa Agrobiology, containing a strain of *Herbaspirillum seropedicae* ZAE 94 (deposited in a culture collection of diazotrophic bacteria Embrapa Agrobiology with the code BR 11417). The seeds were wrapped in peat and dried in the shade, until the time of planting, and 10 g of peat were used per kg of seed. Seedling emergence occurred 10 days after planting.

The nitrogen fertilization was divided three times for the doses of 60 and 100 kg ha^{-1} of N, half of the fertilizer was applied at planting, 1/4 10 days after emergence days seedlings and 1/4 20 days after second application. At dose 20 kg, ha^{-1} of N was divided only twice, because the quantity was small to divide. After the emergence of 60 days, an assessment was made to determine the plant height, number of tillers and the accumulation of fresh and dry weight of plants.

Data were analyzed with SAEG 8.0 (Euclydes, 1983), according to their normality (Lilliefors test) and homogeneity of variance test (Cockran & Bartlet). Given the presuppositions, data were analyzed by ANOVA. The separation of means was done using the statistical test LSD at 5% probability. Test typically used to mean separation, can be applied to the data, the experiment also had a few treatments. The same test is not very restrictive as Tukey. Regression analysis was used to describe the response of plants to different levels of fertilization. For testing, the statistical program Sisvar 5.0 was used (Ferreira, 2003).

Isolation of diazotrophic bacteria

Absolute control of each genotype of rice and brought to Embrapa Agrobiology was collected for the realization of the isolation of diazotrophic bacteria. The samples were separated in aerial part and roots, disinfested superficially in tap water and then distilled water. These were macerated in blender in saline solution, followed by serial dilutions and inserted into vials containing culture media semi-specific nitrogen free, NFb for *Azospirillum* spp. (Döbereiner et al., 1995), JNFb for *Herbaspirillum* spp. (Döbereiner et al., 1995), JMV for *Burkholderia* spp. (Baldani et al., 2000) and LGI for *Azospirillum amazonense* (Döbereiner et al., 1995).

The flasks were incubated at 30°C for 7 days, being considered positive for those counts that showed typical aerotáxica film, near the surface of the medium. The count of the population of diazotrophic bacteria was held by the most probable number (MPN) using the Mc Crady table for 3 repetitions per dilution (Döbereiner et al., 1995). Vials that showed film formation were used in the isolation and purification of bacteria according to Dobereiner et al. (1995) and Baldani et al. (2000).

Morphology of the colonies was observed through the growth of isolated solid media, semi-speciphic (NFB, JNFB and VMY) and rich media (potato dextrose agar), observed morphological characteristics of the colonies such as, borders, coloring and texture (Döbereiner et al., 1995).

The nitrogenase activity of isolated was assessed by acetylene reduction technique (ARA), described by Boddey et al. (1990). The bacteria were grown in bottles with a capacity of 15 ml, containing 5 ml of semi-solid medium semi-specific without pH indicator. These flasks were incubated at 30°C for 48 h. After the formation of the film, the bottles were sealed with rubber stoppers pierceable sub-seal type sterile, 1 ml syringe of air was taken from each bottle and

1 ml of acetylene was also injected. The flasks were incubated at 30°C for an hour and, later, 0.5 ml of the gas phase was introduced into the gas chromatograph with flame ionization, Perkin Elmer model F11 was use to determine the concentration of ethylene in the sample. After determining the ARA, the vials were homogenized in a shaker table, until the complete homogenisation of the film was gotten.

The production capacity of the hormone Auxin (IAA) was analyzed by the microplate method (Sarwar and Kremer, 1995). 1 µL of bacterial culture was used, cultivated previously for 24 h in DYGS medium, and inoculated into 20 ml of DYGS medium supplemented with L-tryptophan, the final concentration of 200 µg ml^{-1} by test tube was gotten. The tubes were kept in the dark, under 150 RPM agitation, with constant temperature of 33°C. Aliquots of 1 ml was withdrawn after 42 h of cultivation, and centrifuged at 10,000 rpm for 15 min.

In U-type plate 96 wells, an aliquot of 150 µl of the supernatant was mixed with 100 µl of Salkowski reagent (1 ml of 0.5 M $FeCl_3$ in 49 ml of 35% perchloric acid), previously prepared. The samples remained in the dark for 30 min under environmental temperature, and read absorbance were made in a microplate reader (Labsystem iems reader MF, Labsystem) at a wavelength of 540 nm. Quantification of indole compounds was evaluated using the calibration curve prepared with serial dilutions of IAA standards (10-80 µg ml^{-1}).

For standardization of the samples, the results were expressed in µg ml^{-1} of IAA per unit of protein. All samples were analyzed in triplicate IAA on boards in U of 96 wells, and the result was due to an average of 3 replicates. For the determination of total protein, the vials were thawed and homogenized again, Elisa plates in U was used at a rate of 20 µl for the sample, 30 µl of sterile distilled water and 50 µl of 1 m NaOH to lyse the cells, then heated for 5 min at 100°C.

To this solution, 900 µl of reagent of Bradford was added, the plates were hustling in vortex and incubated for 30 min at room temperature. After the incubation, the reading of the absorbance at 595 nm was carried out in a spectrophotometer (Bradford et al., 1976). The protein concentration was determined using the standard curve obtained by the absorbance values of known amounts of BSA (bovine serum albumin) at the following concentrations: 0, 2, 4, 8, 12, 16 and 25 mg. ml^{-1}. All samples were analyzed in triplicate and the results obtained by an average of the three readings.

The data were analyzed with the SAEG 8.0 (Euclydes, 1983) regarding normality (Lilliefors test) and homogeneity of variance test (Cockran and Bartlet). The separation of means was done using the Scott Knott statistic test at 5% probability. For testing, statistics program Sisvar 5.0 was used (Ferreira, 2003).

Evaluation of the efficiency of the isolates according to FBN on agronomic characteristics

For the evaluation experiment of efficiency isolates about the agronomic characteristics, FBN used completely randomized design, factorial scheme 4 x 5 willing treatments, where the first factor had the doses applied (0, 20, 60 and 100 kg N ha^{-1}) and the second factor had the inoculation of *Herbaspirillum seropedicae* strain with ZAE 94 (deposited in the collection of cultures of diazotrophic bacteria by Embrapa Agrobiologia with code BR11417), the three strains isolated from the first experiment showed greater efficiency in the production of Auxin and acetylene reduction for each medium and the absence of inoculation. The nitrogen fertilizer in the form of urea, was divided twice, half in planting and the other half 60 days after the emergence of plants. 20 treatments with 4 repetitions for the cultivar BRS Tropical were performed. The experiment was conducted in pots containing 9 kg of soil, conducted with 4 plants in each.

The best strains of each semi-specific medium were selected to prepare the inoculum and subsequently, the BRS Tropical inoculation was carried out. Strains were grown in 50 ml medium DYGS stirring at 150 rpm, with temperature of 30°C for 24 h. The peat was already prepared and sterile, making the mixture of 15 ml of the bacterial suspension to 35 g of peat. Before planting, the seeds were wrapped in peat and dried in the shade at the rate of 10 g per kg of peat seed.

Assessments were made 60 days after seedling emergence, in which plant height, number of tillers and grain during harvest was measured. The data were analyzed with the SAEG 8.0 (Euclydes, 1983) regarding their normality (Lilliefors test) and homogeneity of variance test (Cockran and Bartlet). The separation of means was done using the statistical LSD test at 5% probability, and the use of regression analysis describe the response of plants to different levels of fertilization. For testing, the statistical program Sisvar 5.0 was used (Ferreira, 2003).

RESULTS

Experiment of inoculation of diazotrophic bacteria

The results showed significant differences for inoculation and nitrogen levels on all variables for BRS Tropical (Figure 1a, b, c, d). In all variables, the trend of behavior occurred in a linear fashion with increasing doses of N.

Inoculation with *H. seropedicae* increased by 3.5, 6.0, 6.8 and 2.6% compared to control treatment at doses 0, 20, 60 and 100 kg ha^{-1} of N, respectively for the variable height of rice plants of cultivar BRS Tropical (Figure 1a). For variable number of tillers, the increase was 22.7, 27.8, 31.5 and 12.5% compared to treatment without inoculation with doses of 0, 20, 60 and 100 kg (Figure 1b). The inoculation with diazotrophic bacteria promoted an increase in the number of tillers, probably leading to gains in dry matter production and grain for BRS Tropical.

The accumulation of weight was 32, 36.2, 70.5 and 55.7%, and the dry mass was 27.4, 28.2, 50.8 and 44.2% higher in regarding the treatment without inoculation doses for 0, 20, 60 and 100 kg ha^{-1} N, respectively (Figure 1c, d). The results for BRS Tropical also showed an increase in dry matter accumulation, with gains of 28%. Cultivating BRS, introduced different behavior of Wildcard MG cultivate BRS inoculated treatment Tropical, which is less than the treatment without inoculation and tendency of quadratic behavior, suggesting that there is a maximum dose of N which ensures the quantitative increase of the studied variables. Treatment without inoculation to cultivate, followed the same tendency of cultivating BRS Tropical, where the largest dose of nitrogen applied was responsible for increase of the variables examined (Figure 1 e, f, g, h). Inoculation with strain ZAE 94 provided height of 4.5% less plants to plants that did not receive inoculation (Figure 1 e).

The highest dose of nitrogen applied without inoculation provided increased tillering in 124% compared to treatment without inoculation and no added nitrogen. In inoculated treatment, the maximum number of tillers was observed with the addition of 60 kg.ha^{-1} of N, with an

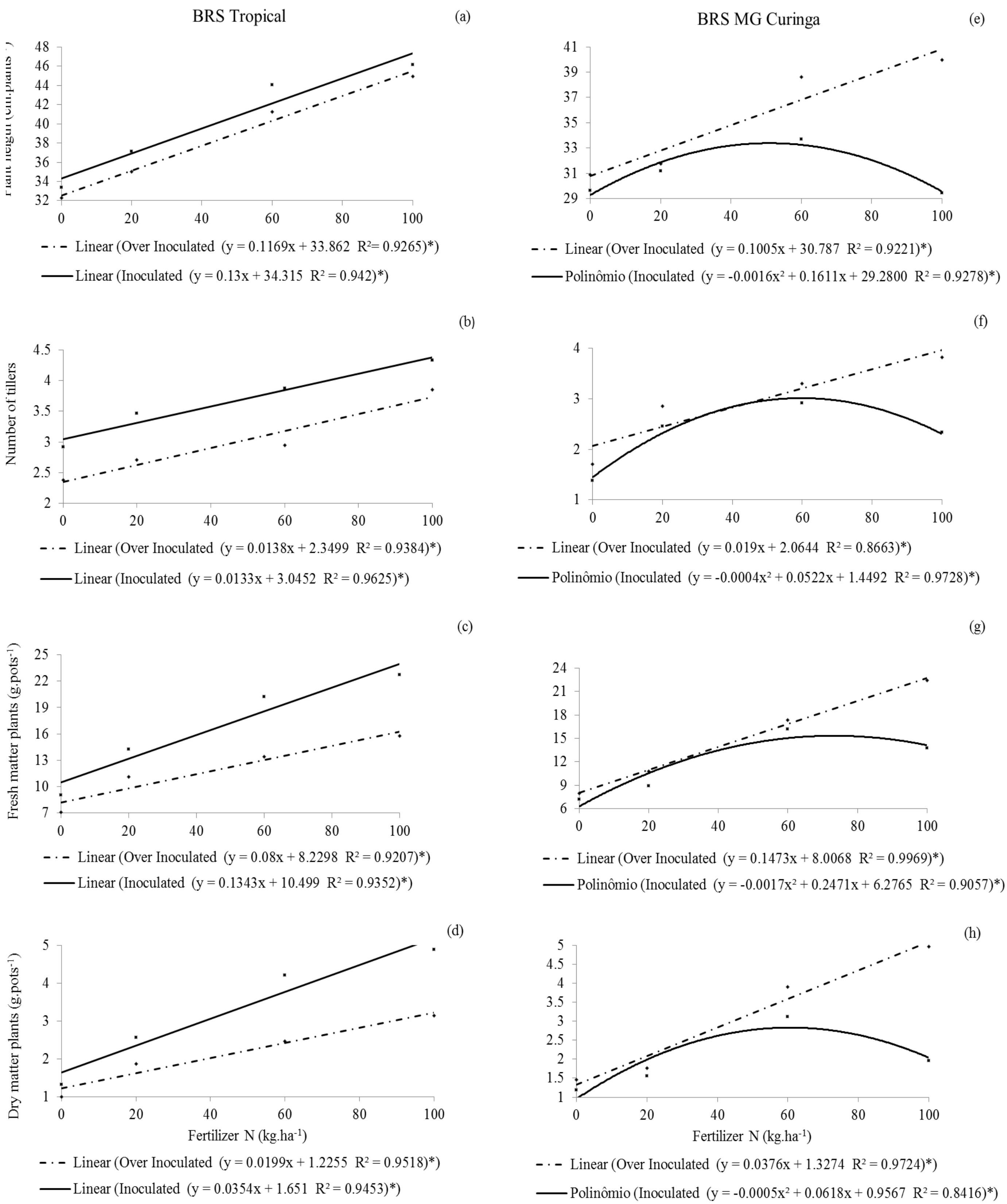

Figure 1. Regression analysis of variables plant height, number of tillers, accumulation for fresh and dry matter plants, depending on the levels of nitrogen (0, 20, 60 and 100 kg ha^{-1}) in BRS Tropical (a, b, c, d) and BRS MG Curinga (e, f, g, h) inoculated or not with strain ZAE 94, under greenhouse conditions (average of 4 $plantas.vaso^{-1}$ and 6 repetitions). Vitoria da Conquista, 2012.

Table 1. Population of diazotrophic bacteria present in plants by the most probable number technique (MPN).

Farm	Location of extraction	JNFB	NFB	JMV
		Number of cells per gram fresh weight (log)		
BRS Tropical	Root	6.65	7.65	7.40
	Aerial Parts	5.65	3.60	6.65
BRS MG Curinga	Root	6.65	6.98	7.65
	Aerial Parts	5.40	5.65	6.18

increase of 112% in relation to the inoculated treatment without N, however, 11.5% lower than the treatment without inoculation with the same amount of N was applied (Figure 1f). The accumulation of weight was 9.7%, 17.6%, 7.1 and 38.6%, and the dry mass was 18.5%, 11.5%, 60.7% and 20.1 below in relation to treatment without inoculation to the doses 0, 20, 60 and 100 kg ha-1 of N, respectively (Figure 1 g, h). Cultivating BRS MG wildcard, inoculated with the strain ZAE 94, plus 20 kg ha^{-1} of N, showed gains in dry matter accumulation around 31%, compared to N-free treatment, but 12% lower than the treatment without inoculation, with the same amount of N applied (Figure 1f). The control treatment showed height of plants 3.4% greater than the treatment medium inoculated with *A. brasilense,* and 2% greater than that with *A. lipoferum*. It was observed that in this experiment, cultivate BRS MG Curing did not answer inoculation with strain of diazotrophic bacteria ZAE 94.

Isolation of Diazotrophic bacteria

In the experiment of isolation of diazotrophic bacteria, populations of diazotrophic bacteria culturing media MV, NFB and JNFB were found. In bacterial populations, LGI was not found. Through the technique of MPN (most probable number), the number of bacteria found in the roots of the plants were higher than the values found in the aerial part of plants (Table 1).

The isolates found in cultivating tropical BRS (Table 1) were from the three means of cultivation used in the experiment, where about 55% of the isolates were from non-disinfested plant roots. Of the total of 31 isolates, 9 were grown in medium JMV from the roots of the plants, and then cultured in medium 8 NFB, and the rest of the isolates were grown in middle JNFB, where 13 were isolated from aerial parts of plants and only 1 was isolated from roots.

The isolation of diazotrophic bacteria coming from the cultivars BRS Topical and BRS MG wildcard, grown in Vitória da Conquista-BA, has obtained 50 isolates, of which 18% were classified as similar to those in the genus *Burkholderia*, 16% similar to the genus *Azospirillum* and 66% similar to those of *Herbaspirillum*. The results found in the three formats evaluated for the production of indole-3-acetic acid (IAA) presented values between 0.261 and 4.347 g.mg μ^{-1} protein. The largest concentrations of indole compounds produced were found in isolates similar to *Herbaspirillum* spp., followed by *Burkholderia* spp. and *Azospirillum* spp.

The ability to make the BNF, via the nitrogenase activity as measured by acetylene reduction technique (ARA), showed that all the selected isolates were able to reduce acetylene to ethylene, proving the efficiency of these bacteria as the potential to fix atmospheric nitrogen to a greater or lesser intensity. The variability among the isolates occurred in the range of the 199.717 and 16.559 mmol/ml protein for an hour before the incubation.

Efficiency of the diazotrophic bacteria as the biological nitrogen fixation (BNF) on the agronomic characteristics

Results showed that 17 B, 37 C and ZAE 94 strains had tendency of quadratic behavior where the dose of 60 kg nitrogen, provided the bigger increase in the variables analyzed, and economy in the amount of N applied. Strain 1A, had the tendency of linear behavior in a negative way, where the increase in the dose of nitrogen provided reduction in variables analyzed, and the control treatment had the tendency of linear behavior, suggesting that increasing the dose of nitrogen ensures the increase of variables. All of these observations were valid for the variables analyzed, except for the number of tillers, where in all treatments the tendency was linear (Figures 2a, b, c, d, e, f).

In a general way, inoculation with diazotrophic bacteria was positive for cultivating Tropical BRS, in relation to control treatment with gains of 9.4 and 3.3% in plant height of 60 DAE, 14.4% in number of tillers, 98% in the dry plants and 3.2% in the grain dry mass weight. The largest dose of N applied in the treatments inoculated, provided smaller gain, in relation to the use of lower doses of nitrogen. The BNF occurs in response to the needs of the plant, and with high level of N-mineral which cause reduction in population of diazotrophic bacteria, and shows no incentive to BNF.

Inoculation showed positive effects and significant superior compared to control treatment, in relation to the dry mass weights. Strain ZAE94, although lower than the

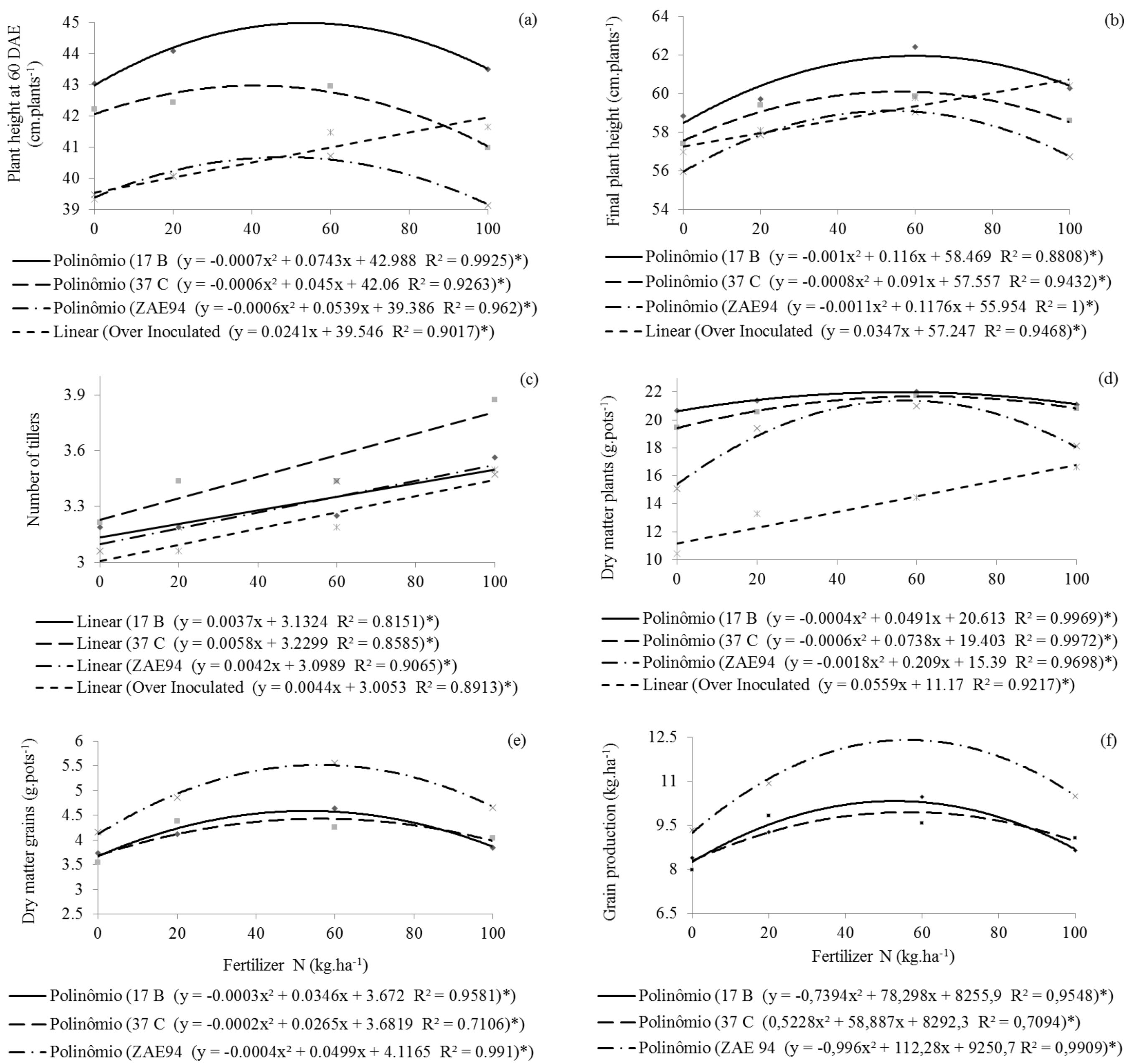

Figure 2. Regression analysis of variable plant height at 60 DAE, final plant height, number of tillers, dry matter accumulation of plants and grains and grain production, depending on the levels of nitrogen (0, 20, 60 and 100 kg.ha^{-1}), BRS Tropical inoculated with strains 1 A, 17 B, 37 C, 94 ZAE and no inoculation under greenhouse (average of 4 plantas.vaso^{-1} and 4 repetitions). Vitoria da Conquista, 2012.

inoculations, 37 C and 17 B was the most responsive to increasing doses of N, with an increase of 30% in relation to the treatment without added N. Furthermore, inoculation with strains 17 B and 37 C, presented showed an increase of 11.3 and 9.5%, (Figure 2d).

Results for the production of grain showed that inoculation with different strains of diazotrophic bacteria was positive and statistically superior to control treatment. At 60 kg ha^{-1} of N, the gains were 7.6 and 28.7% for the 17 strains B and ZAE 94, respectively, in relation to control treatment with the same amount of N applied. Inoculation with strain 37 C was statistically equal to control treatment.

Inoculation with strains 17 B, 37 C and ZAE 94 plus 60 kg ha^{-1} of N, resulted in an increased production of 174.4, 159.4 and 208.5%, respectively. Maximum response on grain production was observed with inoculation with strain ZAE 94 plus 60 kg ha^{-1} of nitrogen, which was exceeding 200% increase. Treatment without inoculation with diazotrophic bacteria showed higher production to treatments inoculated with strains isolated in the doses 0 and 100 kg.ha^{-1} of nitrogen, with gains of up to 17.2 and 52.9%, respectively.

DISCUSSION

Inoculation of diazotrophic bacteria

The results of this study showed that inoculation was beneficial to rice cultivation in the tested conditions according to the results found by Kuss et al. (2008), using the IRGA-420 cultivar at 40 DAS (days after seeding), combination between nitrogen as urea (0, 60 and 120 kg ha^{-1}), inoculation with *Azospirillum brasilense*, isolated UFSM-BD-31-06 and the control, showed no significant differences between treatments for height plants, but inoculation promoted an increase in the variable analyzed.

Ramos et al. (2010), also observed an increase in plant height of 21.4% when plants were inoculated with *Azospirillum lipoferum* (BR strain 11084) and fertilized with 30 kg ha^{-1} N, and 17.6%, when there was only inoculation of maize plants at 30 days after seeding.

The results are in agreement with Oliveira et al. (2007), where only inoculation with diazotrophic bacteria was able to produce more forage *Brachiaria brizantha* cv. Marandu due to the increase in the number of tillers per plant. Guimarães et al. (2003), evaluated the effect of inoculation with diazotrophic bacteria in upland rice, and Sala et al. (2005) in wheat plants also observed an increase in the dry weight of shoots in the presence of inoculation, but found no significant differences between treatments as studied in this work.

Isolation of diazotrophic bacteria

The highest numbers of isolates were obtained from the aerial parts of the plants. Rodrigues et al. (2006), observed a greater population of diazotrophic bacteria in roots of rice, compared to the population found in stems and leaves, which was also observed for the bacteria *Burkholderia* and *Azospirillum*, however divergent results were found for the genus *Herbaspirillum*. Brazil et al. (2005), found a higher number of isolates of *Azospirillum which* was isolated from the roots of irrigated rice plants compared to those isolated from the leaves and stems.

Radwan et al. (2004), found that strains of *Azospirillum* spp. produce three to seven times more indole compounds than *Herbaspirillum* strains, which differs from the result of this study , where the isolates grown in the middle JNFb supposedly classified as belonging to the gender *Herbaspirillum* spp. produced on average 3.36 times more than indole compound isolates of *Azospirillum*. This high variability in the ability to realize the BNF by the technique of acetylene reduction was also observed with bacteria isolated from rice by Rodrigues et al. (2006) and Kuss et al. (2007).

To achieve the second experiment, bacteria were selected from each culture medium processed through the combination of the best production results of indole compounds and acetylene reduction capacity of each culture medium. The selected isolates were: 8 A, 17 B and 37 C respectively.

Evaluation of the efficiency of the isolates according to FBN on agronomic characteristics

The application of low recommended doses to the culture, resulted in higher earnings generating economy, since the reduced amount of N was applied, it was reported by Alves et al. (2003), that the use of small doses of N can benefit BNF. The results found, corroborate the results of Ramos et al. (2010), with significant increases at corn plants height, when they were inoculated with *Azospirillum*, and higher results even when the inoculation was supplemented with N.

Positive effects of inoculation with diazotrophic bacteria were also found by Hall et al. (2008) they evaluated a similar interaction in wheat, observed greater contribution of inoculation on vegetative period with increase in the number of tillers and consequently higher number of panicles per plant. As well, Guimaraes et al. (2010, 2011) found that rice plants inoculated and supplemented with N had higher accumulation of dry matter.

Similar results of this study was published by Ferreira et al. (2003), that reported the inoculation of strain ZAE 94, under field conditions, induced increases in grain yields of 38 and 18%, varieties IR42 and IAC4440, respectively, were compared to the control treatment. Divergent results were found by Dotto et al. (2010), who studied the productivity of maize in response to inoculation with *H. seropedicae* and different levels of N, and observed no significant interactions between inoculation of *H. seropedicae* and levels of N.

The positive effect of inoculation was also observed by Guimarães et al. (2007), who found increases of up to 30% compared to control treatment without inoculation, depending on the cultivar. Ferreira et al. (2010), also observed that inoculation resulted in higher production of 13% compared to control treatment with IAC in 4440. The results found by Jha et al. (2009) corroborate these results, they show that inoculation with diazotrophic bacteria in rice promotes the growth of plants showing the potential of these bacteria as a promising practice in agriculture can reduce the use of nitrogen fertilizers.

CONCLUSION

The isolation afforded 50 isolates, 19 of BRS and 31 of BRS Tropical. The 1 A, 17 B and 37 C showed a better result in the production of auxin, and the ability to reduce acetylene, depending on the medium used. Inoculation with strains of diazotrophic bacteria guaranteed increase in agronomic variables studied. With a greater verified contribution of inoculation when associated with mineral N fertilization. The estimated grain production has shown that inoculation with diazotrophic bacteria provided, there is an increase of up to 208.5%.

Conflict of Interest

The authors have not declared any conflict of interest.

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Response of soil test crop response (STCR) approach as an optimizing plant nutrient supply on yield and quality of Sunflower (*Helianthus annuus* L.)

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The field experiment was carried out in 2013 to 2014 rainy season at the Main Agricultural Research Station, UAS, Raichur, India to study the response of soil test crop response (STCR) approach on the yield and quality of Sunflower (*Helianthus annuus* L.). The experiment was laid out by Randomized Complete Block Design (RCBD) design with three replications. The analysis of variance revealed that the application of fertilizers based on STCR along with foliar application of micro-nutrients significantly recorded higher head diameter, 100 seed weight, , number of filled seed head^{-1},seed filling per cent, seed yield ha^{-1}, Stover yield ha^{-1}, oil content and oil yield ha^{-1}. Further a higher gross return, net returns and benefit-cost ratio (BCR) were observed when compared to the other treatment combinations carried out during the experiment *viz*., recommended dose fertilizer (RDF) of NPK (Control). Overall, we concluded that the input of STCR approach had positive effects on quantitative and qualitative traits of sunflower in conditions of studied area as compared to RDF method.

Key words: Sunflower, recommended dose fertilizer (RDF), soil test crop response (STCR), foliar application, oil content, benefit-cost ratio (BCR).

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is an important oilseed crop fourth next to soybean, groundnut and rape seed in total production of oilseeds of the world. Now a day, the crop has been well accepted by the farming community because of its desirable attributes such as its short duration, photoperiod insensitivity, adaptability to wide range of soil and climatic conditions, drought tolerance, lower seed rate, higher seed multiplication ratio and high quality of edible oil. Recently sunflower has moved to northern parts of the country where the productivity is very high. Karnataka is the leading sunflower producing state in the country and contributes nearly 52% of the

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Table 1. Physical and chemical properties of the soil used in the study (0-30 cm depth).

Textural class	Clay loam
Soil pH	7.96
EC (dSm^{-1})	0.36
CEC (c mol (p^+) kg^{-1})	48.2
Organic carbon (%)	0.62
N (kg ha^{-1})	234.28
P_2O_5 (kg ha^{-1})	39.78
K_2O (kg ha^{-1})	405.02
Mn (ppm)	11.9
Fe (ppm)	3.94
Zn (ppm)	0.26
CU (ppm)	1.01

total area and 40% of the total production in the country. In India, sunflower is grown over an area of 0.83 million ha with a production and productivity of 0.54 million tonnes and 655 kg per ha, respectively during the year of 2012 to 2013 (Anonymous, 2013).

Among the various factors affecting the growth and yield of sunflower, nutrient management practices play a vital role. Presently, the chemical fertilizers are used as a major source of nutrients. But escalating cost, coupled with increasing demand for chemical fertilizers and depleting soil health necessitates the safe and efficient method of nutrient application. Some practices gaining much popularity to enhance and maintain soil fertility and reduce the continuous and over dose use of inorganic fertilizer application which may adversely affect the physico–chemical properties of soil and thereby affect the crop performance. The effective fertilizer recommenddation should consider crop needs and nutrients already available in the soil. Among various methods of fertilizer recommendation such as general recommended dose (GRD), soil test based recommendation, critical value approach, etc., the soil test crop response (STCR) approach for target yield is unique in indicating both soil test based fertilizer dose and the level of yield that can be achieved with good agronomic practices (Singh et al., 2005). The objective of this study was to investigate the effect of fertilizer prescriptions by different approaches on quality and yield production of sunflower.

MATERIALS AND METHODS

The field experiment was carried out in 2013-2014 rainy season at Main Agriculture Research Station (MARS), University of Agricultural Sciences, Raichur, Karnataka, India. Geographically the experiment place is located in North Eastern Dry Zone (Zone-2) of Karnataka State, which falls between 16° 15' N latitude and 77° 20' E longitude with an altitude of 389 m above mean sea level. The soil of the experimental site belongs to medium black with clay loam texture with pH 7.96.Other characteristics of the soil are given in (Table 1). Climate of Raichur region with the average maximum and minimum temperature is 33 and 21.5°C respectively and average rain fall of 62.72 mm.

Agronomic practices such as weeds, pests and diseases control except supplementary irrigation performed as recommended in the area and were done during growth season. Two seeds per hill were dibbled by maintaining 30 cm space between two hills in a row. To ensure even stand and to maintain required plant population, gap filling was done 13 days after sowing. Only one plant per hill was retained after thinning. Placement of solid fertilizer in the soil was applied as basal dose (half of nitrogen and full dose of phosphorus and potassium) was applied at the time of sowing and remaining half of nitrogen was applied at 30 DAS. NPK (19:19:19) was applied at 5 kg ha^{-1}, Zn and Fe were applied in the form of $ZnSO_4$ and $FeSO_4$ at 2.5 kg ha^{-1} and finally Boron was applied at 1 kg ha^{-1} as foliar application according to the treatment details (T_4, T_5, T_6, T_7, T_8 and T_9). The soil analysis results reveals that available nitrogen was low, therefore addition of 12.5 kg ha^{-1} to the recommended level of nitrogen (90 kg ha^{-1}) was done (103 kg ha^{-1}) and medium in available phosphorous (90 kg ha^{-1}) and potassium (60 kg ha^{-1}) was applied for T_2. The experiment has nine treatments, viz.

1. 100% Recommended dose fertilizer of NPK (T_1),
2. Soil test based NPK (T_2),
3. STCR approach (T_3),
4. Foliar spray of nutrients NPK (19:19:19 at 1% spray at 15, 30, 45 and 60 DAS) + Zn (0.5 %) and Fe (0.5%) sprays at 30, 45 and 60 DAS + B (0.2%) sprays at 50% flowering (T_4),
5. 100% RDF + Foliar spray of nutrients NPK, Zn, Fe and B (T_5),
6. 75 % Recommended NPK + Foliar spray of nutrients NPK, Zn, Fe and B (T_6),
7. 50% Recommended NPK + Foliar spray of nutrients NPK, Zn, Fe and B (T_7),
8. Soil test based NPK+ Foliar spray of nutrients NPK, Zn, Fe and B (T_8) and
9. STCR approach+ Foliar spray of nutrients NPK, Zn, Fe and B (T_9).

The trial was laid out in a Randomized Complete Block Design (RCBD) with three replications. The targeted yield equations developed for the sunflower crop under AICRP on STCR scheme were used for the calculation of fertilizer N, P_2O_5 and K_2O by considering the targeted yield of 25 q ha^{-1} was done by the equation listed below.

F.N. = 8.38 T- 0.57 SN ($KMnO_4$ - N)
F.P_2O_5 = 8.05 T- 6.00 SP_2O_5 (Olsen's - P_2O_5)
F.K_2O = 9.87 T- 0.47 SK_2O (NH_4OAC - K_2O)

Using the above fertilizer adjustment equations the quantity of fertilizer nutrients required for achieving 25 q ha^{-1} grain yield of sunflower was worked out. The fertilizer N, P_2O_5 and K_2O applied for T_3 was 96:165:57 kg ha^{-1}.

RESULTS AND DISCUSSION

Yield attributes

Different nutrient management practices have a significant effect on yield attributes, *viz*. head diameter (cm), number of filled seed $head^{-1}$, seed filling (%) and 100-seed weight (g) (Table 2). Among the nutrient management treatments, it was significantly higher (28.14 cm, 520.74 and 76.77% and 5.11 g, respectively) under STCR approach + Foliar spray of NPK at 1% + $ZnSO_4$ at 0.5% + $FeSO_4$ at 0.5% and B at 0.2% (T_9) than

Table 2. Head diameter, number of filled seed per head, seed filling and test weight, of sunflower as influenced by different nutrient management practices.

Treatments	Head diameter (cm)	Number of filled seeds head^{-1}	Seed filling (%)	100 seed weight (g)
T_1: RDF (control)	22.27	416.05	65.43	4.63
T_2: Soil test based NPK (STL method)	24.17	456.24	69.20	4.78
T_3: STCR approach (Yield target: 25 q/ha)	26.53	513.53	74.39	4.85
T_4: Foliar spray of NPK + $ZnSO_4$ + $FeSO_4$ and B	19.03	200.42	39.01	3.57
T_5: T1 + T4	23.27	431.38	67.00	4.70
T_6: 75 % RDF + T4	20.33	387.20	62.56	3.90
T_7: 50 % RDF + T4	19.43	370.62	55.68	3.77
T_8: T2 + T4	25.47	501.42	72.55	4.80
T_9: T3 + T4	28.14	520.74	76.77	5.11
S.Em. ±	1.12	26.94	1.43	0.12
C.D. at 5%	3.38	57.27	4.29	0.37

Recommended dose of fertilizer (RDF) rate 90:90:60 kg NPK ha^{-1}, Foliar spray of NPK at 1% at 15, 30, 45 and 60 DAS, $ZnSO_4$ and $FeSO_4$ at 0.5% at 30, 45 and 60 DAS and Boron at 0.2% rates at 50% flowering.

Table 3. Seed yield, Stover yield, oil content and oil yield of sunflower as influenced by different nutrient management practices.

Treatments	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
T_1: RDF (control)	1636	2541	33.37	546
T_2: Soil test based NPK (STL method)	1730	2611	35.13	608
T_3: STCR approach (Yield target: 25 q/ha)	1860	2767	37.83	704
T_4: Foliar spray of NPK + $ZnSO_4$ + $FeSO_4$ and B	975	1970	30.77	300
T_5: T1 + T4	1675	2596	34.07	571
T_6: 75% RDF + T4	1564	2493	31.63	495
T_7: 50% RDF + T4	1392	2372	31.02	432
T_8: T2 + T4	1814	2719	37.10	673
T_9: T3 + T4	1919	2814	38.53	740
S.Em. ±	35.81	48.96	0.71	16.00
C.D. at 5%	107.36	146.81	1.52	48.00

Recommended dose of fertilizer (RDF) rate 90:90:60 kg NPK ha^{-1},Foliar spray of NPK at 1% at 15, 30, 45 and 60 DAS, $ZnSO_4$ and $FeSO_4$ at 0.5% at 30, 45 and 60 DAS and Boron at 0.2% rates at 50% flowering.

the rest of the treatments but statistically on par treatments T_3 (STCR approach) and Soil test based NPK + Foliar spray of NPK at 1% + $ZnSO_4$ at 0.5% + $FeSO_4$ at 0.5% and B at 0.2% (T_8) (Table 2). Similar results were reported for maize by Bakery et al. (2009). The positive effect on sunflower of foliar spray with micro and macro nutrients were observed by Barmaki et al. (2009), who revealed that the yield and yield components of sunflower were increased as a result of foliar spray with Fe, Zn and B. Significant increase in number of filled seeds per head and total number of seeds per head are increased with zinc and boron application. Similar type of synergetic effect was also reported on sunflower by Patil et al. (2006).

Seed and stover yield

Seed and Stover yield (kg ha^{-1}) was significantly influenced by different nutrient management practices. According to the treatments T_9 (STCR approach + Foliar spray of NPK at 1% + $ZnSO_4$ at 0.5% + $FeSO_4$ at 0.5% and B at 0.2%) recorded significantly higher(1919 and 2814 kg ha^{-1}, respectively) was significantly higher yield recorded as compared to 100 per cent RDF (T_1) and the rest of the treatments but statically it was on par (1860 and 2767 kg ha^{-1}, respectively) with T_3 (STCR approach) and $T_{8:}$ Soil test based NPK + Foliar spray of NPK at 1% + $ZnSO_4$ at 0.5% + $FeSO_4$ at 0.5% and B at 0.2% (1814 and 2719 kg ha^{-1}, respectively) (Table 3). The results were in conformity with Kazem et al. (2013), who reported that the use of foliar spray on sunflower crop along with complete fertilizer increased grain yield significantly.

Aravinda et al. (2010) indicated that the response of sunflower to application of B, Fe or Zn was seen on the seed yield. The application of B (0.3%) significantly influence the seed yield, resulting of 983 kg ha^{-1} to 757 kg ha^{-1}as is done on the control, increase of 226 kg ha^{-1} (23%) being provided as very significant statistically. It was attributed mainly due to proper seed filling as number of unfilled seeds was minimum in B (0.3%) treatment. The application of Zn or Fe also caused significant yield increase over control due to improvement in growth and yield attributes. Combined application of any two micronutrients could not increase the yield over single application of boron.

Oil content and oil yield

Different nutrient management practices were significantly influenced on the oil content (%) and oil yield (kg ha^{-1}) of the sunflower crop. Treatment T_9 (STCR approach + Foliar spray of NPK at 1% + $ZnSO_4$ at 0.5% + $FeSO_4$ at 0.5% and B at 0.2%) was significantly higher oil content and oil yield (38.53% and 739.58 kg ha^{-1}, respectively) as compared to 100% RDF (T_1) and the rest of the treatments but the oil content (%) was on par with T_3 (STCR approach) and Soil test based NPK + Foliar spray of NPK at 1% + $ZnSO_4$ at 0.5% + $FeSO_4$ at 0.5% and B at 0.2% (T_8) and oil yield (kg ha^{-1}) was on par only with T_3 (STCR approach). The lowest oil content and oil yield was recorded in treatment only with foliar spray of NPK at 1% + $ZnSO_4$ at 0.5% + $FeSO_4$ at 0.5% and B at 0.2 (T_4) (Table 3). Foliar fertilization with balanced agrofond (N60 P60 K60) fertilized significantly influence on oil production due to sufficient amount of nutrient to fulfill the crop demand (Mihaela and Valeriu, 2010; Kazem et al., 2013).

Conclusion

The results of this experiments revealed that soil test based fertilizer application for desired yield targets with foliar spray of micronutrients significantly increased quality and yield production of sunflower crop. This positive effect may be due to their effects on root growth, nutrients uptake, simulation of many different enzymes related to photosynthesis, efficient response to plant nutrient requirement, integrated supply of nutrients from different sources and improved nutrient supply. The specific yield equation based on soil health will not only ensure sustainable crop production but will also steer the farmers towards economic use of costly fertilizer inputs.

Conflict of Interest

The authors have not declared any conflict of interest.

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