Pak. J. Bot., 53(3): 967-973, 2021. DOI: http://dx.doi.org/10.30848/PJB2021-3(44)

SPATIAL ARRANGEMENTS AND SEEDING RATES INFLUENCE BIOMASS PRODUCTIVITY, NUTRITIONAL VALUE AND ECONOMIC VIABILITY OF MAIZE (*ZEA MAYS* L.)

ASIF IQBAL[1], MUHAMMAD AAMIR IQBAL[2*], MOHAMED F. AWAD[3,4], MUHAMMAD NASIR[1], AYMAN EL SABAGH[5] AND MUZAMMIL H. SIDDIQUI[2]

[1]*Department of Agronomy, Faculty of Agriculture, University of Agriculture Faisalabad, Pakistan*
[2]*Department of Agronomy, Faculty of Agriculture, University of Poonch Rawalakot (AJK), Pakistan*
[3]*Department of Biology, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia*
[4]*Botany and Microbiology Department, Faculty of Science, Al-Azhar University, Egypt*
[5]*Department of Agronomy, Faculty of Agriculture, University of Kafrelsheikh, Egypt*
[*]*Corresponding author's email: muhammadaamir@upr.edu.pk*

Abstract

Climate change and global warming have necessitated re-investigating production technology package of field crops for boosting their performance. Forage maize herbage yield, nutritional value and profitability were assessed by executing a field trial under semi-arid conditions. Agronomic yield attributes, green herbage yield, dry matter biomass, nutritional quality traits and economic turnouts were taken as response variables. The field trial was conducted using the factorial arrangement of RCBD. Different spatial arrangements (15, 30 and 45 cm) and seeding rates (80, 100 and 120 kg ha^{-1}) were tested to determine the most productive combination. Maize planted in row spacing of 30 cm using 100 kg ha^{-1} seed rate remained superior by producing the maximum fresh biomass (49.82 t ha^{-1}) and dry matter yield (13.18 t ha^{-1}). The same treatment combination also improved the nutritional value of maize by increasing fat and ash contents while decreasing crude fiber. This treatment combination was followed by 120 kg ha^{-1} seed rate sown in 30 cm apart rows, while the seed rate of 80 kg ha^{-1} planted in 15 cm apart rows remained inferior to other treatments. In terms of economic performance, 100 kg ha^{-1} seed rate sown in 30 cm spaced rows remained unmatched by generating the maximum net earnings of US$ 567 with the highest benefit-cost ratio (2.39). Thus, it is inferred that the forage potential of maize can be maximally exploited by using the seed rate of 100 kg ha^{-1} sown in 30 cm apart rows under semi-arid agro-climatic conditions.

Key words: Fodder yield, Plant population, Row spacing, Economic turnouts, Crude protein and ash.

Introduction

Climate change, unsustainable farming systems and increasing populace have seriously threatened and compromised the food and nutritional security in South Asian states (Shahzad *et al.*, 2020; Iqbal *et al*., 2019a; Khaliq *et al.*, 2019). Interest is again revitalizing to develop and mold agronomic technology packages which may impart sustainability to existing profit-oriented farming along with boosting crops productivity and economic viability (Iqbal *et al*., 2018a; Iqbal *et al*., 2015a; William & Curt, 2002). The milk and meat productivity is directly dependent on animal nutrition which gets affected by sustainability of forage production (Iqbal *et al*., 2015b; Iqbal & Iqbal, 2015). Globally, maize (*Zea mays* L.) occupies pivotal position among forage crops by supplying abundant quantity of lush green forage with acceptable quality traits (Maqsood *et al.*, 2020; Riffat & Ahmad, 2020; Iqbal *et al*., 2017; Ali 2016; Ali *et al.*, 2015; Maddonni & Otegui, 2001; Bavec & Bavec, 2002). In South Asian countries, maize forage productivity has been suboptimal especially owing to obsolete agronomic technology package which needs thorough investigation to cope with emerging threats of climate change (Iqbal *et al*., 2019b; Alam *et al*., 2017). The research needs are again revitalizing to develop and mold crops production technology packages which may impart sustainability to existing profit-oriented farming by boosting their productivity and economic viability (Iqbal *et al*., 2018a; William & Curt, 2002).

Among agronomic yield attributes, plant population is the single most vital parameter which determines of productivity and profitability of forage maize (Thapa *et al.*, 2020; Iqbal & Ahmad, 2015; Akman, 2002). Plant population gets affected by inter-row spacing which also imparts significant influence on root growth, herbage yield and nutritional value of cereal forages (Li *et al*., 2004). Maize vegetative growth was adversely affected by closer spacing of rows as it gave rise to intense inter-plant competition for inputs which led to significant yield reduction (Lambe *et al*., 1998). Sub-optimal plant population, excessive vegetative growth and plants lodging along with severe weed infestation were recorded when the inter-row spacing was inappropriately increased (Li *et al*., 2015). Shahoo & Panda (1999) inferred that nine maize varieties sown in row × plant spacing of 70 cm × 20 cm remained superior by yielding the maximum green forage during spring and autumn seasons. In contrast, the maximum yield was given by maize planted in 60 cm apart rows, while inter-plant spacing was kept at 45 cm (Maddonni & Otegui, 2006). However, it has also been revealed that maize productivity was significantly enhanced when row × plant spacing of 40 × 30 cm was maintained, while the rest of spatial arrangements (60 × 13 cm and 40 × 25 cm) performed below par (Sarlangue *et al*., 2007). Another contradictory finding has been reported where 35 cm apart rows of maize resulted in the highest biological yield in comparison to 45 cm spaced rows (Reta-Sanchez *et al*., 2015). Moreover, row spacing was instrumental in maintaining the plant population of maize which indirectly determined agro-botanical traits and biological yield of spring planted maize (Testa *et al*., 2016). Thus keeping in view the contradictory findings, fresh field investigations are necessary to be executed to ascertain the most productive spatial arrangement for achieving varietal potential of forage maize yield as per varietal potential information under varying pedo-climatic conditions.

In addition to spatial arrangements, plant population of all crops including forage maize is also affected by the seeding rates (Andrzej *et al.*, 2020; Maddonni & Otegui, 2004; Naik *et al*., 2017). There are also contradictory findings regarding seeding rate and its impact on agronomic attributes, herbage yield, nutritive value and economic performance of forage maize under varying agro-ecological conditions. The seed rate for producing 32000 plants per hectare was found to be necessary to achieve the maximum productivity of maize, however water availability and soil fertility status in addition to seed germination rate were recommended to be considered for cereal forages (Graybill *et al*., 1991). In contrast, seeding rate of maize was reported to have no significant influence on crude protein and fiber contents of forage maize under irrigated conditions (Ayub *et al*., 1999). Again contradictory findings were reported where 150 kg ha^{-1} seed rate of maize remained statistically non-significant to 125 kg ha^{-1} in terms of green biomass production, while increasing seed rate had adverse impact on protein content of forage maize (Song *et al*., 2016). Previously, it has also been reported that all agronomic traits, herbage yield and nutritional quality parameters were influenced by seeding rate of maize (Charles & Charles, 2006). Along with biomass production and nutritional value, economic turn outs also constitute central position for increasing area under forage maize. Profits tend to decrease due to lower productivity coupled by doubling production costs which has led to continuously decreasing area under forage crops as farmers prefer to switch to cash crops (Sani *et al*., 2008).

Varying environmental variables due to climate change, intensive farming induced soil deterioration, decreasing soil fertility caused by unsustainable use of synthetic fertilizers and contradictory findings regarding the optimal combination of spatial arrangement and seeding rate of maize make imperative to conduct fresh field investigations. The postulated hypothesis was that different seeding rates and spatial arrangements differ in their impact while complimentary combination of seeding rate and planting geometry may assist to achieve forage maize productivity, nutritional quality and net income. Thus, the prime goal of this field trial was to assess forage maize response to different seeding rates and spatial arrangements with respect to total herbage yield, nutritional value and economic viability.

Materials and Methods

Experimental site's description: This trial was executed at the Agronomy Research Fields of University of Agriculture Faisalabad (31°25′45″ N 73°4′44″ E), Pakistan. The climate of the experimental site is sub-humid while soil is classified as Haplic Yermosols (Iqbal *et al*., 2018b). The composite soil samples were subjected to analyses to determine mechanical and chemical characteristics of the experimental soil. The soil sampling was done from the corners and the center of the experimental unit up to 30 cm depth as per recommended protocols (Table 1). The soil of the experimental site was sandy clay loam and was found to be severely deficient in all macro-nutrients (N, P and K) as well as soil organic matter. The experimental soil had pH of 7.8.

Table 1. The mechanical and chemical characteristics of the experimental soil before sowing determined from soil samples collected from 0-30 cm depth.

Soil characteristics	Recordings
Organic matter	0.79%
pH	7.8
Electrical conductivity	1.74 dSm^{-1}
Nitrogen (total)	282.1 mg kg^{-1}
Phosphorous (available)	7.0 mg kg^{-1}
Potassium(available)	183.8 mg kg^{-1}
Sand	58%
Silt	20%
Clay	22%
Textural class	Sandy clay loam

Experiment's details: Maize (cv. Pak Afgoi-2003) seeds were obtained from Sargodha Forage Research Institute, Punjab, Pakistan. The field trial was comprised of three spatial arrangements (15×15, 30×30 and 45×45 row spacing) and three seeding rates of 80, 100 and 120 kg ha^{-1}). Thus, nine treatment combinations were tested in this field investigation. The factorial arrangement of the randomized complete block design was employed to execute the field experiment. There were four replications of each experimental plot. The net size of experimental plots was 6 × 14 m. Green and dry herbage yield, nutritional value and economic performance were selected as response variables.

Crop husbandry: A fine seed bed was prepared through three cultivations followed by planking to pulverize the soil. Single super phosphate (45 kg ha^{-1} P_2O_5) and sulphate of potash (20 kg ha^{-1} K) were applied as basal dose before crop sowing, while urea (100 kg ha^{-1} N) was applied in three equal splits. Half of the urea was broadcasted at sowing time, while rest of the urea was applied in two equal splits with subsequent irrigations. There were four flood irrigations and weeds were controlled manually (14 and 22 DAS) at early growth stages of maize. All agronomic practices except those under evaluation were uniformly applied to all experimental plots.

Recording of response variables: Forage maize yield attributes were recorded at the harvesting time (65 days after sowing at pre-flowering stage). Fifteen randomly selected maize plants were selected for recording the agro-botanical traits such as plant height with tailor's measuring plastic tap, stem diameter using vernier caliper, number of leaves, fresh plant leaf area using portable leaf area meter and fresh and dry weights with the help of movable balance. Plant population was determined by counting plants in an area of 2 m^2, while tripod-tied spring balance was used to measure herbage yield of each plot by harvesting all plants and then was converted into tons per hectare. In order to determine dry matter, 100 g sample of chopped forage was oven-dried at 105°C until it had attained constant weight and was subsequently converted into tons per hectare. The nutritional quality traits were also recorded using standard techniques and protocols as suggested by Anon., (2003).

Economic analyses: To economically analyze the treatment combinations, total cost of production (TCP) was calculated as suggested by Iqbal *et al*., (2016);

$$TCP = FE + VE \quad (1)$$

where, FE represents fixed expenditures containing rent of land, employed labor, irrigation costs, harvesting expenditures, cost of transportation to market), VE donates variable expenditures (seed price).

Gross profit (GP) and net profit (NP) for each treatment were computed as;

$$GP = GFY \times PM \quad (2)$$

where, GFY and PM represent green forage yield (t ha^{-1}) and local market price of maize forage (US$).

$$NP = GP - TC \quad P \quad (3)$$

The benefit-cost ratio (BCR) was calculated using equation;

$$BCR = GP / TCP \quad (4)$$

Statistical analyses: Barlett's test at probability level of 5% indicated a non-significant interaction of treatment × year, as homogeneous variances were observed. Thus pooling of the data was done for statistical analysis as factorial arrangement of randomized complete block design. Data pertaining to yield attributes, herbage yield, dry matter biomass and nutritional quality were analyzed and compared using Fisher's technique of variance analysis (ANOVA) with three factors of seed rate, spatial arrangement and seed rate × spatial arrangement interaction. The comparison of treatments means was done by employing the Duncan's multiple range test at 5% probability level (Steel *et al*., 1997). The correlation coefficients were used to find out the relationship among agronomic yield traits and herbage biomass using Microsoft's Excel program (Iqbal *et al*., 2016).

Results and Discussion

Green biomass and dry matter yield: The agro-botanical traits serve as important indicators for determining plant growth and predicting forage yield of cereals (Iptas & Acar, 2006; Ogola *et al*., 2005; Li & Li, 2004; Nawab *et al*., 1999). In this study, seed rates had significant ($p \leq 0.05$) influence on maize population as the plots receiving 120 kg ha^{-1} seeds recorded the maximum plant population; however it had non-significant interaction with the spatial arrangements (Table 2). The rest of yield attributes such as plant height, stem girth, leaf area, fresh weight and dry weight were significantly ($p \geq 0.05$) effected by their interactive effect, however the number of leaves was the only exception. The spatial arrangement of 30 cm using 100 kg ha^{-1} seed rate remained outstanding by recording the maximum agronomic variables which led to the maximum herbage yield and dry matter biomass. However, fresh and dry weights of maize plants were at par to their equivalents at the seeding rate of 100 kg ha^{-1} sown in 45 cm spaced rows (Table 2). The highest seeding rate (120 kg ha^{-1}) under the narrowest row spacing (15 cm) performed below par in terms of all yield traits and herbage biomass. The correlation analyses revealed direct relationship of all yield attributes with herbage yield indicating the need to breed new maize varieties having higher genetic potential for vegetative growth (Fig. 1).

The reason for sub-optimal performance of the highest seeding rate (120 kg ha^{-1}) could be owing to intensive inter-plant competition for farm inputs especially fertilizers, while sub-optimal plant population was reported to impart drastic impacts on effective utilization of farm inputs (Ogola *et al*., 2005). In contrast to these findings, previously it was reported that 80 kg ha^{-1} seed rate of maize produced higher biomass compared to 60 kg ha^{-1}, however seed rate increment gave the reduced forage yield due to competition for limited soil moisture (Amanullah *et al*., 2009; Esechie, 2009; Davi *et al*., 1995). Ayub *et al*., (1999) inferred that spatial arrangements had no influence on the number of leaves of forage maize and it was suggested that number of leaves per plant seemed to be genetically controlled trait for which agronomic management practices remained ineffective. Spatial arrangement were reported to impart significant influence on herbage yield while, close spacing between the rows such as 15 and 20 cm part rows confronted higher competition. It was also observed that widely spaced rows including 45, 60 and 70 cm apart rows recorded lower efficiency of applied nutrients due to lesser plant population (Addo *et al*., 2011). In contrasting findings, seeding rates were recorded to have no impact on herbage yield, however higher nutrient use efficiency was recorded for closely spaced rows which led to higher biomass production of cereal forages (Turgut *et al*., 2005; Shieh & Lu, 1992).

Nutritional value: The nutritional quality of forage crops determines their value especially protein content occupies the central place on nutritional scale (Ciampitti & Vyn, 2010). The highest protein content (8.37%) was recorded for 100 kg ha^{-1} seed rate while the lowest protein was recorded by 80 kg ha^{-1} seed rate (Table 2). Spatial arrangements and its interaction with seed rate remained non-significant as far as protein content of forage maize was concerned. In contrast, the interaction effect of spatial arrangement and seed rate was found to be significant ($p \geq 0.05$) for the crude fiber content. The highest fiber was observed for seed rate of 80 kg ha^{-1} planted under all row spacing, while the combination of seed rate (100 kg ha^{-1}) and spatial arrangement (30 cm) resulted in the minimum fiber content. Contrary to previous trend, the maximum ash content (8.51%) was produced by 45 cm spaced rows which remained at par to 15 cm row spacing, 30 cm apart rows gave the minimum ash content of forage maize. Previously, an inverse relationship has been reported between protein and fiber contents of forage crops as increment in protein reduced the fiber content (Farnham, 2001). Moreover, high protein and low fiber of forages were associated with higher forage quality which effectively increased milk and meat production. The significant impact of spatial arrangements and seeding rate on ash of forage maize was probably owing to difference in minerals absorption which caused an increment in ash content of forage maize (Rakesh *et al*., 2016; Lambe *et al*., 1998).

Table 2. Yield attributes, herbage yield and nutritional value of maize under varying seed rates and spatial arrangements (combined analysis).

Seeding rates (kg ha^{-1})	Plant population (m^{-2})	Plant height (cm)	Leaves $plant^{-1}$	Stem girth (cm)	Plant leaf area (cm^2)	Fresh plant weight (g)	Dry plant weight (g)	Herbage yield (t ha^{-1})	Dry matter biomass (t ha^{-1})	Protein (%)	Fiber (%)	Ash (%)
80	27.63 c	168.10 b	10.89 ab	1.48 c	2098.7 b	387.20 c	32.25 b	37.86 c	11.42 c	7.36 b	28.63 b	8.89 a
100	33.64 b	176.80 a	11.30 a	1.61 a	2377.4 a	458.66 a	32.93 a	45.66 a	13.40 a	8.48 a	25.41c	8.48 b
120	36.68 a	169.72 b	10.82 b	1.55 b	2193.0 b	425.23 b	30.69 b	43.61 b	12.83 b	7.69 b	31.15 a	7.93 c
Significance	*	**	**	**	**	**	**	**	**	*	**	**
Spatial arrangements (cm)												
15	30.39	169.90 b	11.78	1.40 c	2185.6 b	407.10 b	31.53 b	38.36 c	11.15 c	7.60	30.81 a	8.60 a
30	33.23	171.13 a	12.30	1.45 a	2275.3 a	429.82 a	33.69 a	42.29 a	11.90 a	7.81	29.47 c	8.47 b
45	31.30	172.54 a	11.73	1.43 b	2180.9 b	413.67 b	32.45 ab	40.14 b	11.43 b	7.64	30.25 b	8.5 ab
P≥0.01	NS	*	NS	*	*	*	*	*	*	NS	*	-
Seeding rate (t ha^{-1}) × Spatial arrangements (cm)												
80×15	25.27	164.53 e	11.63	1.32 e	2018.0 c	374.33 f	31.25 cd	36.57 e	9.97 f	7.25	30.76 a	9.08 a
80×30	27.97	166.00 de	11.80	1.37 e	2128.3 bc	418.00 d	33.37 ab	38.45 d	10.65 de	7.37	26.73 e	8.83 b
80×45	26.33	170.47 c	11.61	1.36 e	2149.7 b	395.67 e	31.83 c	38.53 d	10.42 ef	7.12	25.57 e	8.97 ab
100×15	31.67	174.33 b	11.00	1.45 cd	2377.3 a	436.33 b	32.73 b	42.26 c	12.80 bc	8.14	31.68 c	8.54 c
100×30	34.17	179.20 a	11.67	1.55 a	2497.0 a	456.33 a	34.94 a	49.82 a	14.08 a	8.75	27.12 f	8.46 c
100×45	31.77	174.17 b	10.90	1.51 b	2280.7 b	450.00 ab	33.98 ab	44.86 b	13.19 b	8.23	31.41 b	8.43 c
120×15	30.99	167.53 cde	10.56	1.41 de	2156.0 b	417.67 cd	28.71 d	42.57 c	12.18 cd	7.48	29.31 d	8.10 d
120×30	34.23	168.20 cd	11.03	1.46 c	2214.7 b	422.33 c	32.42 b	44.80 b	12.71 b	7.38	29.39 d	7.99 d
120×45	32.50	170.13 c	10.53	1.46 c	2175.3 b	402.33 de	31.61 c	43.34 bc	12.84 b	7.54	29.42 d	8.00 d
	NS	**	NS	*	*	*	*	*	*	NS	*	*

Year × Spatial Arrangements × Seeding rate

Non-significant

Values having different lettering within the columns vary at p<0.05

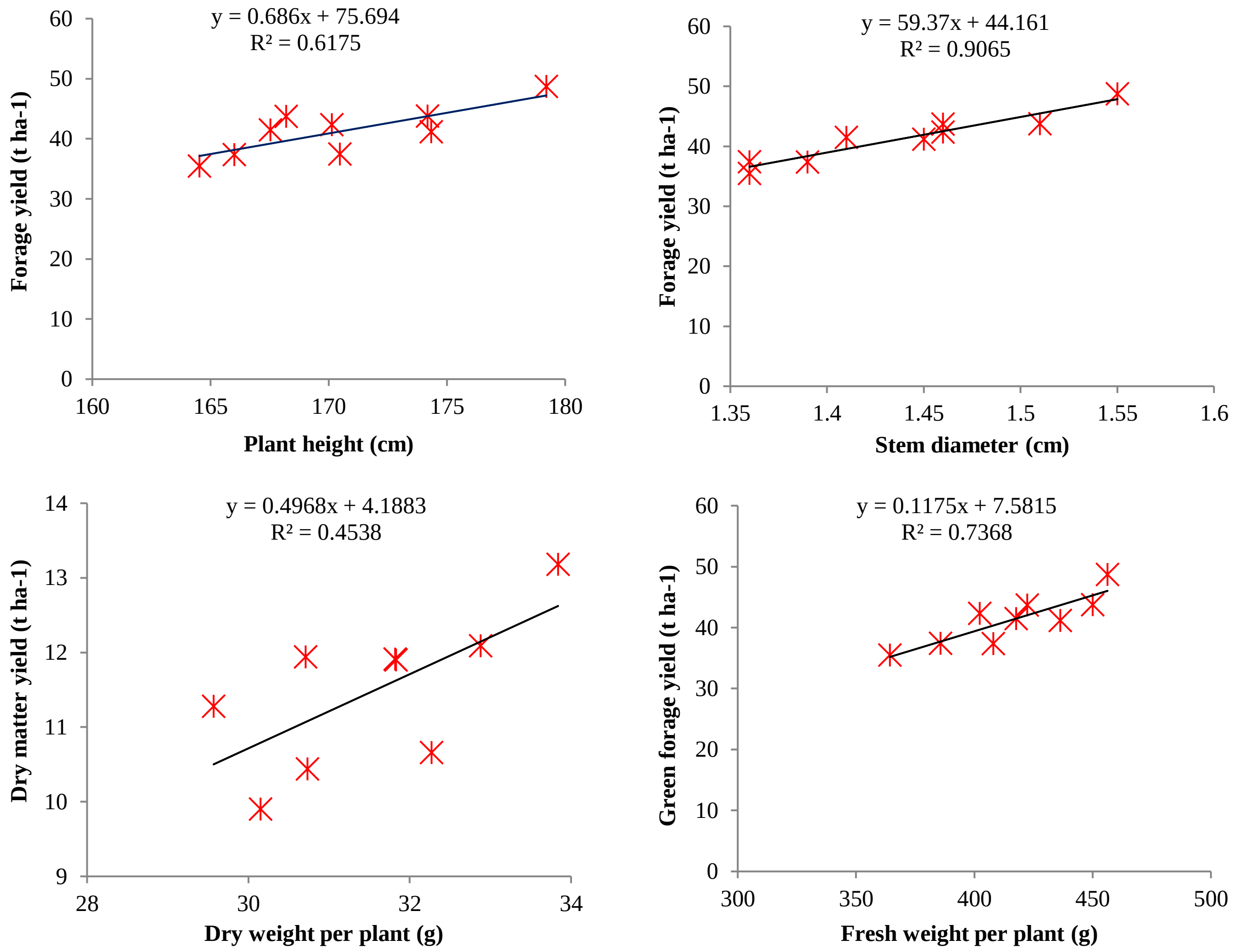

Fig. 1. Yield attributes correlation with herbage and dry matter yields of maize sown using varying seeding rates and spatial arrangements.

Table 3. Economic viability of forage maize planted using different seed rates under varied spatial arrangements (pooled analysis).

Treatments	TCP	GP	NP	BCR
80×15	388.24	709.40	321.16	1.82
80×30	388.24	747.00	358.76	1.92
80×45	388.24	748.60	360.37	1.93
100×15	406.79	823.20	416.41	2.02
100×30	406.79	974.40	567.62	2.39
100×45	406.79	875.20	868.41	2.15
120×15	424.53	829.57	405.04	1.95
120×30	424.53	874.00	449.47	2.05
120×45	424.53	846.80	422.27	1.99

TCP= Total cost of production in US$ ha^{-1}, GP= Gross profit in US$ ha^{-1}, NP= Net profit US$ ha^{-1}, BCR= Benefit: cost

Economic viability: The appraisal of forages production on economic dimension is of the utmost importance to cease the decreasing area under forages by making them compatible to cash crops in terms of economic turn outs (Iqbal *et al*., 2016; Roy *et al*., 1992). The seed rate of 100 kg ha^{-1} sown in 30 spaced rows generated the maximum gross income of US$ 974 along with the net income of US$ 567) (Table 3). The unmatched herbage yield recorded by this combination of spatial arrangement and seeding rate might be attributed for generating the maximum economic turnouts. Economically, seed rate of 120 kg ha^{-1} followed it. The seed rate of 80 kg ha^{-1} sown under all spatial arrangements could not perform at par to higher seeding rates. Prior research findings also revealed that optimization of seed rate and planting geometries was instrumental for boosting nutrient and water use efficiencies of forage crops which resulted in achieving the maximum herbage yield as per varietal potential and ultimately profitability was multiplied significantly. Moreover, suboptimal seeding rates and spatial arrangements caused depletion of economic returns of cereal forages owing to sub-optimal plant population which led to crop switching by farmers (Ayub *et al*., 2003).

Among economic indicators of crop production, the benefit-cost ratio (BCR) is consider vital to determine the additional income generated by each treatment which could also be used as an indicator to assess economic viability of applied treatments. The seed rate of 100 kg ha^{-1} sown in 30 cm apart rows resulted in the maximum BCR of 2.39, while the same seeding rate sown in 45 cm apart rows with BCR of 2.15 followed it. It was followed by forage maize planted in 30 cm apart rows by using 120 kg ha^{-1} seed rate (Table 3). The results revealed that seed rate of 80 kg ha^{-1} recorded the minimum BCR under all planting geometries. These findings completely corroborate with those of Alam *et al*., (2017), who recommended that optimal use of seed rate and planting geometry increased profitability by boosting herbage yield and it was suggested to re-investigate the spatial arrangements and seeding rates under different agro-climatic conditions in order to achieve the maximum economic returns from cereal forages.

Conclusions

Climate change and decreasing economic turnouts have necessitated modifying and re-optimize the production technology for forage maize. The seed rates and spatial arrangements imparted significant influence on yield attributes and herbage yield of forage maize. The crop sown using sate rate of 100 kg ha^{-1} in 30 cm apart rows resulted in the maximum biomass and nutritional value of forage maize which led to the highest gross and net incomes. Moreover, the postulated hypothesis of the field trial was rejected partially as seed rate increment proved helpful up to 100 kg ha^{-1}, while over than this seed rate reduced the herbage yield and economic turn outs. Moreover, closely spaced rows remained superior but up to 30 cm and further narrowing of rows adversely affected the herbage yield and economic viability of maize. Thus, the combination of 100 kg ha^{-1} seeding rate planted in 30 cm rows could be recommended in order to fully exploit the forage maize potential. It is also suggested to conduct further in-depth field investigations to evaluate more spatial arrangements and their impact on water and nutrient use efficiencies.

Acknowledgement

The highest appreciation to Taif University, Taif, Saudi Arabia, for partially funding the study under the Taif University Researchers Supporting Project number TURSP-2020/111.

References

Addo, Q.A., A. Darkwa and G.K. Ocloo. 2011. Growth analysis of component crops in a maize-soybean intercropping system as affected by time of planting and spatial arrangement. *J. Agric. Biol. Sci.,* 6: 34-44.

Akman, Z. 2002. Effect of tiller removing and plant density on ear yield of sweet corn (*Zea mays*). *Pak. J. Biol. Sci.,* 5: 906-908.

Alam, S., K. Aaqil, J.C. Li, I.A. Mhummad, A. Umair and A.J. Sikander. (year missing). Response of maize grown under high plant density; performance, issues and management – A critical review. *Adv. Crop Sci. Technol.,* 5: 121-131.

Ali, A.A., A. Iqbal and M.A. Iqbal. 2015. Forage maize (*Zea mays* L.) germination, growth and yield get triggered by different seed invigoration techniques. *World J. Agric. Sci.,* 12: 97-104.

Ali, N. 2016. Plant density and intra-row spacing effects on phenology, dry matter accumulation and leaf area index of maize in second cropping. *Biol.,* 62: 46-57.

Amanullah, K.R., A. Khalil and K.K. Shad. 2009. Plant density and nitrogen effects on maize phenology and grain yield. *J. Plant Nut.,* 32: 246-260.

Andrzej, A., M. Piotr, K. Stanislaw, K. Zdzislaw, L.A. Józef and C.D. Jan. 2020. Effect of seeding rate on selected physical parameters and biomass yield of maize. *Chilean J. Agric. Res.,* 80: 171-180.

Anonymous. 2003. AOAC-Official Methods of Analysis. 17th Edition. Association of Official Analytical Chemists. Inc. Arlington, Virginia, USA. PP. 225-234.

Ayub, M., R. Ahmed, M.A. Nadeem, B. Ahmed and R.M.A. Khan. 2003. Effect of different levels of nitrogen and seed rates on growth yield and quality of maize fodder. *Pak. J. Agric. Sci.,* 40: 140-143.

Ayub, M., R. Mahmood, A. Tanveer and M.S. Sharar. 1999. Effect of seeding density on the fodder yield and quality of two maize varieties. *Pak. J. Biol. Sci.,* 2: 664-666.

Bavec, F. and M. Bavec. 2002. Effect of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars. *Eur. J. Agron*., 31: 151-159.

Charles, A.S. and S.W. Charles. 2006. Corn response to nitrogen rate, row spacing, and plant density in Eastern Nebraska. *Agron. J.,* 98: 529-535.

Ciampitti, I.A. and T.J.A. Vyn. 2010. A comprehensive study of plant density consequences on nitrogen uptake dynamics of maize plants from vegetative to reproductive stage. *Field Crops Res.,* 121: 2-18.

Davi, C.M., B.R. Reddy, P.M. Reddy and S.C.S. Reddy. 1995. Effects on nitrogen levels and plant density on yield and quality of JKHY-1 cotton. *Cur. Agric. Res.,* 8: 144-146.

Esechie, H.A. 2009. Effect of planting density on growth and yield of irrigated maize (*Zea mays*) in the Batinah coast region of Oman. *J. Agric. Sci.,* 119: 165-169.

Farnham, D.E. 2001. Row spacing, plant density, and hybrid effects on corn grain yield and moisture. *Agron. J*., 93: 1049-1053.

Graybill, J.S., W.J. Cox and D.J. Otis. 1991. Yield and quality of forage maize as influenced by hybrid, planting date and planting density. *Agron. J.,* 83: 559-564.

Iptas, S. and A.A. Acar. 2006. Effects of hybrid and row spacing on maize forage yield and quality. *Plant Soil Environ.,* 52: 515-522.

Iqbal, A.; M.A. Iqbal, A. Iqbal, Z. Ahmad, Z. Ahmad, R.N. Abbas and R.D. Khan and M. Faisal. 2017. Boosting forage yield and quality of maize (*Zea mays* L.) with multi-species bacterial inoculation in Pakistan. *Phyton-Int. J. Exp. Bot.,* 86: 84-88.

Iqbal, M.A. and A. Iqbal. 2015. Overviewing forage shortage for dairy animals and suitability of forage sorghum for ensiling. *Glob. Vet.,* 14: 173-177.

Iqbal, M.A. and M.M. Ahmad. 2015. Boosting spring planted irrigated maize (*Zea mays* L.) grain yield with planting patterns adjustment. *Am-Eur. J. Agric. Environ. Sci.,* 15: 315-319.

Iqbal, M.A., A. Hamid, I. Hussain, M.H. Siddiqui, T. Ahmad, A. Khaliq and Z. Ahmad. 2019a. Competitive indices in cereal and legume mixtures in a South Asian environment. *Agron. J.,* 111: 242-249.

Iqbal, M.A., A. Hamid, T. Ahmad, I. Hussain, S. Ali, A. Ali and Z. Ahmad. 2019b. Forage sorghum-legumes intercropping: Effect on growth, yields, nutritional quality and economic returns. *Bragantia.,* 78: 82-95

Iqbal, M.A., A. Iqbal and R.N. Abbas. 2018b. Spatio-temporal reconciliation to lessen losses in yield and quality of forage soybean (*Glycine max* L.) in soybean-sorghum intercropping systems. *Bragantia.,* 77: 283-291.

Iqbal, M.A., A. Iqbal, M. Ayub and J. Akhtar. 2016. Comparative study on temporal and spatial complementarity and profitability of forage sorghum-soybean intercropping systems. *Custos e Agronegocio.,* 14: 2-18.

Iqbal, M.A., A. Iqbal, N. Akbar, H.Z. Khan and R.N. Abbas. 2015a. A study on feed stuffs role in enhancing the productivity of milch animals in Pakistan- Existing scenario and future prospect. *Glob. Vet.,* 14: 23-33.

Iqbal, M.A., B. Ahmad, M.H. Shah and K. Ali. 2015b. A study on forage sorghum (*Sorghum bicolor* L.) production in perspectives of white revolution in Punjab, Pakistan: Issues and future options. *Am-Eur. J. Agric. Environ. Sci.,* 15: 640-647.

Iqbal, M.A., B.J. Bethune, A. Iqbal, R.N. Abbas, Z. Ahmad, H.Z. Khan and B. Ahmad. 2017. Agro-botanical response of forage sorghum-soybean intercropping systems under atypical spatio-temporal pattern. *Pak. J. Bot.,* 49: 987-994.

Iqbal, M.A., M.H. Siddiqui, S. Afzal, Z. Ahmad, Q. Maqsood and R.D. Khan. 2018a. Forage productivity of cowpea [*Vigna unguiculata* (L.) Walp] cultivars improves by optimization of spatial arrangements. *Rev. Mex. de Cienc. Pec.,* 9: 203-219.

Khaliq, A., M.A. Iqbal, M. Zafar and A. Gulzar. 2019. Appraising economic dimension of maize production under coherent fertilization in Azad Kashmir, Pakistan. *Custos Agronegocio.,* 15: 243-253.

Lambe, D.L., S.M. Patil, D.J. Jiotode and S.O. Drainage. 1998. Effect of irrigation levels and row spacing on yield of rabi maize (*Zea mays* L.). *J. Soil Crops,* 8: 95-99.

Li, J., R.Z. Xie, K.R. Wang, B. Ming and Y.Q. Guo. 2015. Variations in maize dry matter, harvest index, and grain yield with plant density. *Agron. J.,* 107: 829-834.

Li, M. and W. Li. 2004. Regulation of fertilizer and density on sink and source and yield of maize. *Sci. Agric. Sin.,* 37: 1130-1137.

Maddonni, G.A. and M.E. Otegui. 2004. Intra–specific competition in maize: Early establishment of hierar– chies among plants affects final kernel set. *Field Crops Res.,* 85: 1-13.

Maddonni, G.A. and M.E. Otegui. 2006. Intra–specific com– petition in maize: Contribution of extreme plant hierarchies to grain yield, grain yield components, and kernel composition. *Field Crops Res.,* 97: 155-166.

Maddonni, G.A., M.E. Otegui and A.G. Cirilo. 2001. Plant population density, row spacing, and hybrid effects on maize canopy architecture and light attenuation. *Field Crops Res.,* 71: 183-193.

Maqsood, Q., R.N. Abbas, M.A. Iqbal, S.K. Aydemir, A. Iqbal and A. El Sabagh. 2020. Overviewing weed management practices to reduce weed seed bank and to increase maize yield. *Planta Daninha.,* 38:e20199716

Monneveux, P., P.H. Zaidi and C. Sanchez. 2005. Population density and low nitrogen affects yield–associated traitsin tropical maize. *Crop Sci.,* 45: 535-545.

Naik, P.K., B.K. Swain, E.B. Chakurkar and N.P. Singh. 2017. Effect of seed rate on yield and proximate constituents of different parts of hydroponics maize fodder. *Indian J. Anim. Sci.,* 87: 109-112.

Nawab, K., M. Ahsan and H. Rashid. 1999. Effect of different plant spacing on grain yield of maize. *J. Res.,* 15: 147-150.

Neylon, J.M., T.L. Ebling, C.C. Taylor, M.P. Lynch, M.A. Reddish, M.I. Endres and L. Kung. 2002. The effects of height of cutting, hybrid and stage of maturity at harvest on the nutritive value of corn silage for lactating dairy cows. *J. Dairy Sci.,* 85: 383-388.

Neylon, J.M., T.L. Ebling, C.C. Taylor, M.P. Lynch, M.A. Reddish, M.I. Endres and L. Kung. 2002. The effects of height of cutting, hybrid and stage of maturity at harvest on the nutritive value of corn silage for lactating dairy cows. *J. Dairy Sci.,* 85: 383-388.

Ogola, J.B., T.R. Wheeler and P.M. Harris. 2005. Water use of maize in response to planting density and irrigation. *S. Afr. J. Plant Soil,* 22: 116-121.

Rakesh, K., S. Magan, S.K. Tomar, B.S. Meena and D.K. Rathore. 2016. Productivity and nutritive parameters of fodder maize under varying plant density and fertility levels for improved animal productivity. *Indian J. Animal Res.,* 50: 199-202.

Reta-Sánchez, D.G., J.S. Serrato-Corona, H.M. Quiroga-Garza, A. Gaytán-Mascorro and J.A. Cueto-Wong. 2015. Effects of plant height and row spacing on kenaf forage potential with multiple harvests. *Phyton-Int. J. Exp. Bot.,* 84: 262-271.

Riffat, A. and M.S.A. Ahmad. 2020. Sulfur: a multifunctional elementthat improvesnutritional value of maize grains. *Pak. J. Bot.,* 52: 2031-2041.

Roy, S.K. and P.K. Biswas. 1992. Effect of plant density and detopping following silking in cob growth, fodder and grain yield of maize. *J. Agric. Sci.,* 119: 297-301.

Sani, B.M., K.O. Oluwasemire and H.I. Mohammed. 2008. Effect of irrigation and plant density on the growth, yield and water use efficiency of early maize in the Nigerian savanna. *ARPN J. Agric. Biol. Sci.,* 3: 33-40.

Sarlangue, T., F.H. Andrade, P.A. Calivino and L.C. Purcell. 2007. Why do maize hybrids respond differently to variations in plant density. *Agron. J.,* 99: 984-991.

Shahoo, S.C. and M.M. Panda. 1999. Determination of optimum planting geometry for baby corn (*Zea mays* L.). *Indian J. Agric. Sci.,* 69: 664-665.

Shahzad, H., M. Iqbal, S. Bashir and M. Farooq. 2020. Management of soil physical health and carbon dynamics in maize cultivated field through organic amendments. *Pak. J. Bot.,* 52: 1251-126.

Shieh, G.T. and H.S. Lu. 1992. Effect of planting density on forage and grain yield of maize with different kernel types. *Agric. Res. China.,* 41: 233-240.

Steel, R.G.D., J.H. Torrie and D.A. Deekey. 1997. Principles and procedures of statistics: A Biometrical Approach. 3rd Ed. Mc Graw Hill Book Co. Inc. New York. p. 400-428.

Thapa, S., Q. Xue and B.A. Stewart. 2020. Alternative planting geometries reduce production risk in corn and sorghum in water limited environments. *Agron. J.,* 112: 3322-3334.

Turgut, I., A. Duman, U. Bilgigli and E. acikgoz. 2005. Alternate row spacing and plant density effects on forage and dry matter. *J. Agron. Crop Sci.,* 191: 1465-151.

William, D.W. and D.T. Kurt. 2002. Row width and plant density effect on corn forage hybrids. *Agron. J.,* 94: 326-330.

(Received for publication 1 May 2019)