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Agronomic Performance of Paprika (*Capsicum annuum* L.) in Response to Varying Plant Populations and Arrangement in the Smallholder Sector of Zimbabwe

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Abstract: The effect of plant population and spatial arrangement on the agronomic performance of paprika (*Capsicum annuum* L.) was studied on-farm in the Chinyika Resettlement Area (CRA) of Zimbabwe during 2000-2003 cropping seasons. The treatments were factorial combinations of four plant population densities (35000, 50000, 65000 and 80000 plants ha^{-1}) and two plant arrangements (single and double-row planting). The experimental design was a randomized complete block design with four replications. When plant population increased from 35000 through to 65000 plants ha^{-1} total fruit yield increased 21.6-64.7% but yield declined 23.7% at 80000 plants ha^{-1} in the 2000/01 season. Significant response to plant population was up to 80000 plants ha^{-1} in the 2001/02 season. In the 2000/01 season, marketable fruit yield increased by 48.1% when plant population was increased from 35000 to 65000 plants ha^{-1}. Total fruit yield per plant and number of fruits per plant responded significantly ($p<0.05$) to variation in plant population in the 2000/01 season up to 65000 plants ha^{-1}. Above this population fruit yield per plant and plant height declined significantly. In the 2001/02 season, number of fruits per plant and plant height did not respond to variation in plant population. Generally, row arrangement had no significant influence on fruit yield except total fruit yield and number of fruits/plant that were higher under 2-row planting than under one-row in the 2000/01 season. Results suggest that increasing plant population from 55000 to above 65000 plants ha^{-1} caused significant increase in total fruit yield and that 2-row planting can give higher fruit yields per hectare and per plant as against the one-row planting.

Key words: Plant arrangement, paprika, *Capsicum annuum* L., plant population, fruit yield, yield components

INTRODUCTION

Smallholder producers of paprika in Zimbabwe face a number of production problems, one of which is poor field establishment under the dryland system (Ogunlela and Koomen, 2005) in Zimbabwe. Poor field establishment can result from high transplant mortality, sub-optimal plant population and serious weed challenge. To overcome this obstacle, there would be need to determine optimum planting densities for paprika production under the dryland system, while also avoiding artificial drought caused by supra-optimal plant population levels.

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Pepperoncini pepper plants grown at the narrowest spacings generally produce the smallest plants and leaf and stem biomass and result in more upright plants, which produce the highest fruit yields and counts per hectare but the lowest fruit yield per plant (Motsenbocker, 1996). Other types of pepper, such as bell and Jalapeno chili peppers, grown at higher plant populations produced higher fruit yields per unit area while fruit set per plant decreased linearly in the field or greenhouse (Jovicich *et al*., 2003, 2004; Sheldrick, 2003). In the same way, Decoteau and Graham (1994) reported that growth and reproductive potential of each pepper plant were reduced at high population densities but that large plant numbers compensated for this.

From an on-station field experiment under supplementary sprinkler irrigation in Harare, Zimbabwe, Ogunlela and Koomen (2005) observed that number of fruits per plant in paprika declined significantly with increasing plant density but fruit number per plant declined ouly in one of two years. Unfortunately, there is dearth of literature information on on-farm research on paprika pepper plant population and plant arrangement.

Arrangement of plants in a field can have a rather strong influence on how such plants would respond to various factors to bring about their effects on crop performance. Plant spatial arrangement can have influence on fruit yield and quality in some pepper types. Decoteau and Graham (1994) have reported that the plant density and plant arrangement (i.e., number of plant rows per ridge) influenced cayenne pepper plant dry weight, stem diameter and plant width. Plants grown at the widest in-row spacing and one row of plants per ridge had the highest dry weight and thickest stems. The number of plant rows per bed and in-row plant spacing affected red fruit and total fruit yields. Red, green and total fruit yields per plant increased linearly when in-row spacing was increased from 15 to 60 cm. Conversely, as number of plant rows per bed increased from one to two, red and total fruit yield per plant decreased.

Smallholder farmers in Zimbabwe grow their paprika crops either in single or double rows on the ridge. The two-row planting arrangement was developed for mechanically harvested pepper, to facilitate movement of tractors and other machines for spraying and harvesting operations. What remains unclear, however, is whether or not the two-row planting arrangement is beneficial to the smallholder system for paprika production with respect to fruit yield and quality. Furthermore, most reported work on these aspects has been on pepper types other than paprika and in on-station experiments either in the field or in the greenhouse. All these are in contrast to on-farm situation such as that in which the present investigation was conducted. The present investigation was therefore conducted on-farm with a view to studying the response of paprika pepper to different plant populations and plant arrangements with respect to fruit yield and yield components.

MATERIALS AND METHODS

The study was conducted in the Chinyika Resettlement Area (CRA) in Northeastern part of Zimbabwe, which covers three agro-ecological zones (Vincent and Thomas, 1960) and an area within lat. 18° 12′ and 18° 17′ S, long. 32° 09′and 32° 24′ E and altitudes ranging between 1300 and 1700 m above sea level. The soils were granitic sands of the kaolinitic order and moderately to strongly leached (Nyamapfene, 1991). The area has a subtropical climate with three seasons, namely, a dry winter, followed by a dry hot season and then a rainy season (Vincent and Thomas, 1960).

The treatments tested were made up of factorial combinations of plant population levels (35,000, 50,000, 65,000 and 80,000 plants ha^{-1}) and two plant spatial arrangements (one row and two rows per ridge) in a randomized complete block design with four replications. When transplanting seedlings onto the field, they were arranged either in one row or two rows along the ridges according to treatment. To obtain the desired plant population, the right combination of a fixed between-ridge spacing of 0.9 m and varying in-row spacings in combination with either one row or two rows per ridge:

- **P1:** 35,000 plants ha^{-1} (31.7 and 63.4 cm in-row for single row and two rows per ridge, respectively)
- **P2:** 50,000 plants ha^{-1} (22.2 and 44.4 cm in-row for single row and two rows per ridge, respectively)
- **P3:** 65,000 plants ha^{-1} (17.0 and 34.0 cm in-row for single row and two rows per ridge, respectively)
- **P4:** 80,000 plants ha^{-1} (13.8 and 27.6 cm in-row for single and two rows per ridge, respectively)

In cases where there were two rows of plants on the ridge, the two rows were separated by a space of 0.1 m.

The experiment was conducted over three cropping seasons, namely, 2000/01, 2001/02 and 2002/03, at two sites in each season, with the exception of 2000/02 when it was conducted only at Mugadza in Chinyika West. Transplanting was done on 28 December 2000 but almost all the transplants died due to drought stress. Re-transplanting was done on 31 January 2001. Weeding was done at 16 and 46 days after transplanting. Ammonium nitrate (35% N) was applied at a rate of 350 kg N ha^{-1} in a single dose. Harvesting of fruits was done on 10 May 2001 and all the fruits, that is, ripe and unripe, were harvested at once. The seed used in the trials was that of cultivar PapriKing, which is a high yielding and most popular variety in Zimbabwe.

During the 2001/02 season, the experiment was conducted at two sites, namely, Mugadza in Chinyika West and Chikodzo in Chinyika East. At Mugadza transplanting was done on 23 November 2001. Weeding was done twice, at 34 and 57 DAT. A mixture of 30 g copper oxychloride (active ingredient (a.i.) copper oxychloride, 850 g kg^{-1}) and 30 g Dithane M45 (85%WP a.i. mancozeb (800 g kg^{-1}) per 15 L of water was sprayed to control bacterial leaf spot (*Xanthomonas campestris* pv *vesicatoria*) in all plots. Harvesting was done twice, on 1 and 29 March 2002. Apart from fruit yield data, the other parameters taken were number of fruits per plant, plant height and number of plants per net plot. At Chikodzo transplanting was done 18 December 2001. Weeding was done only once, at 30 DAT. No disease and pest control measures were taken on the trial. Harvesting was done on 30 March 2002.

In the 2002/03 season, transplanting was done on 12 December 2002 at Kunyongana and 15 December 2002 at Sanhi. Ammoniun nitrate top dressing was done on 5 February 2003 at a rate of 350 kg ha^{-1}. First harvesting was done on 27 March 2003 and the final one on 17 April 2003. The harvested fruits in all cases were allowed to air-dry and then graded into marketable and unmarketable categories before weighing. Other parameters recorded were total and marketable yields per hectare, number of fruits per plant, plant height and mean fruit mass.

Data collected were subjected to one-way Analysis of Variance (ANOVA) to test for significance of treatment effects (Snedecor and Cochran, 1980). Where the F-tests were significant the various treatment means were separated using the Duncan's Multiple Range Test (Steel *et al*., 1997).

RESULTS

The results for ouly one site per season are presented here. Variations in plant population significantly influenced total fruit yield per hectare at Mugadza in the 2000/01 and 2001/02 seasons (Tables 1, 2). As plant population increased from 35,000 plants per hectare total fruit yield per hectare increased significantly up to 65,000 plants ha^{-1} but declined as plant population increased to 80,000 plants per hectare in the 2000/01 season.

When plant population increased from 35000 plants ha^{-1} to 50000 and 65000 plants ha^{-1}, total fruit yield was increased 21.6 and 64.7%, respectively. Total fruit yield however declined 23.7% as plant population increased to 80,000 plants ha^{-1}. Marketable fruit yield did not respond to plant

Table 1: Main effects of plant population and number of rows per ridge on paprika fruit yield, fruit yield per plant and number of fruits per plant at Mugadza in the 2000/01 season

	Fruit yield (kg ha^{-1})			
Treatment	Total	Marketable	Fruit yield (g $plant^{-1}$)	No. fruits $plant^{-1}$
Plant population ('000 plants ha^{-1})				
35	578c	265	12.4ab	6.9c
50	703b	357	13.1ab	8.3bc
65	952a	393	14.7a	10.0a
80	726b	311	9.7b	9.0ab
LSD (0.05)	222	-	3.3	1.5
Plant arrangement (No. rows $ridge^{-1}$)				
Single-row	642b	312	12.1	7.6b
Double-row	838a	350	12.9	9.4a
Significance	*	ns	ns	**
LSD (0.05)	157	-	-	1.1

ns, *, **Not significant, significant at $p \le 0.05$ and $p \le 0.01$ respectively. Means within the same category in a column and followed by different letter(s) are significantly different at $p \le 0.05$ according to the Duncan's multiple range test

Table 2: Main effects of plant population and number of rows per ridge on paprika fruit yield and number of fruits per plant at Mugadza in the 2001/02 season

	Fruit yield (kg ha^{-1})		
Treatment	Total	Marketable	No. fruits $plant^{-1}$
Plant population ('000 plants ha^{-1})			
35	286c	162	6.4
50	343bc	193	5.9
65	409b	210	4.9
80	521a	272	4.1
LSD (0.05)	109	-	-
Plant arrangement (No. rows $ridge^{-1}$)			
Single-row	392	201	5.1
Double-row	386	218	5.5
Significance	ns	ns	ns
LSD (0.05)	-	-	-

ns, *, **Not significant, significant at $p \le 0.05$ and $p \le 0.01$, respectively. Means within the same category in a column and followed by different letter(s) are significantly different at $p \le 0.05$ according to the Duncan's multiple range test

population increase. Both fruit yield $plant^{-1}$ and number of fruits $plant^{-1}$ increased significantly ($p \le 0.05$ and $p \le 0.01$, respectably) with increase in plant population. Increasing plant population from 35,000 plants ha^{-1} to 50,000 and 65,000 plants ha^{-1} increased fruit yield $plant^{-1}$ 5.6 and 18.6%, respectively. Corresponding increases in number of fruits $plant^{-1}$ were 20.3 and 44.9%. These two parameters declined as plant population level reached 80,000 plants ha^{-1} (Table 1) as fruit yield $plant^{-1}$ declined 34.0% when plant population increased from 65,000 to 80,000 plants ha^{-1}.

Paired-row planting produced significantly higher total fruit yield and number of fruits $plant^{-1}$ over the single-row planting. The two parameters were increased 30.5 and 23.7%, respectively. Both marketable fruit yield and fruit yield per plant did not respond to spatial arrangement of the plants (Table 1).

Fruit yields were generally not as good in the 2001/02 season as they were in the preceding season (Table 2). At the same site in 2001/02, it was only total fruit yield per ha that responded significantly ($p \le 0.01$) to plant population. Response to increasing plant population was significant up to the highest plant population level of 80,000 plants ha^{-1}. Total fruit yield increased 19.9, 43.0 and 82.2% as plant population increased from 35,000 plants ha^{-1} to 50,000, 65,000 and 80,000 plants ha^{-1}, respectively (Table 2). None of the three parameters responded to spatial arrangement of the plants.

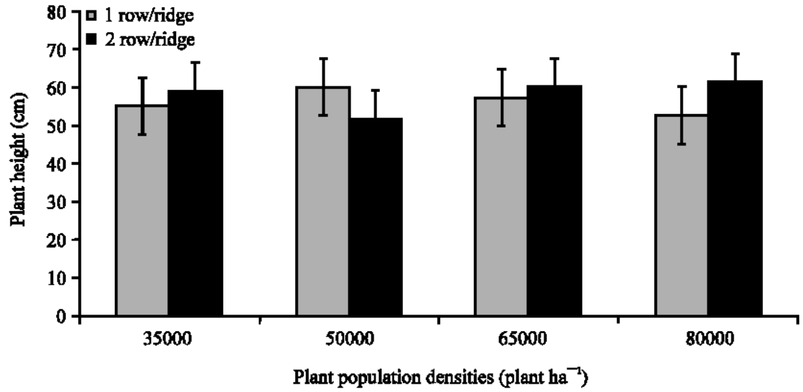

Fig. 1: Interaction effect of plant population and plant spatial arrangement on paprika plant height at the Mugadza site in the 2000/01

Table 3: Main effects of plant population and number of rows per ridge on paprika fruit yield, number of fruits per plant, plant height and mean fruit mass at Kunyongana in the 2002/03 season

	Fruit yield (kg ha^{-1})				
Treatment	Total	Marketable	Plant height (cm)	No. fruits plant^{-1}	Mean fruit mass (g)
Plant population ('000 plants ha^{-1})					
35	513	318	63.3	9.4	4
50	564	348	60.9	9.5	3.8
65	564	341	64.1	8.8	3.6
80	560	368	63.8	9.3	3.5
Plant arrangement (No. rows ridge^{-1})					
Single-row	557	340	63.4	9.6	3.6
Double-row	563	348	62.7	8.9	3.8
Significance	ns	ns	ns	ns	ns

ns: Not significant between means at $p \leq 0.05$

There was significant interaction between plant population and spatial arrangement for plant height at the Mugadza site in the 2000/01 season (Fig. 1). At the highest plant population level of 80,000 plants ha^{-1}, the paired-row arrangement produced taller paprika plants. However, at the lower plant population levels, the single-row arrangement produced either similar or shorter plants as the paired-row arrangement.

At the Kunyongana site in the 2002/03 season, the various parameters that were assessed failed to respond to either plant population or spatial arrangement of plants and such parameters include total and marketable fruit yields, plant height, number of fruits per plant and mean fruit mass (Table 3). Furthermore, for the three cropping seasons for which the study lasted, fruit yields were generally better in the 2002/03 season and at the Kunyongana site than in the 2001/02 season at the Mugadza site but lower than in the 2000/01 season at the latter site.

DISCUSSION

At the Mugadza site in 2000/01 season, total fruit yield in paprika increased as plant population was increasing as a result of increase in the number of plants per unit area, which translated to more fruits per unit area. Consequently, the significant increase in total fruit yield can be attributed to interplay of factors, which resulted in significant increase in number of fruits per unit area and number of fruits per plant. Increase in fruit yield per plant was therefore a response to significant increase in the number of fruits per plant as plant population increased from 35,000 to 65,000 plants ha^{-1}. Higher plant densities (which is synonymous to narrower spacings) have earlier been found to bring about higher fruit yields per unit planting area in hot chili pepper (Aliyu, 2002; Shirai and Hagimori, 2004), Jalapeno pepper (Sheldrick, 2003), sweet pepper (Jovicich *et al*., 1999), bell pepper (Jollife and Gaye, 1995) and paprika pepper (Cavero *et al*., 2001; Ogunlela and Koomen, 2005). The literature has shown that yield responses to plant density can be quite substantial. It has been reported that plots with higher plantings have produced higher yields than those with the standard density by as much as 67%. While paprika plant population was increasing, it is most likely that both inter-plant and intra-plant competition was at play and that up to the 65,000 plants ha^{-1} level, such competition was not to a degree that total fruit yield would be depressed. However, as plant population was increased to 80,000 plants ha^{-1}, the degree of competition for various enviroumental resources reached a point where they became detrimental to total fruit yield hence the observed decline. There is tendency for paprika fruit yield to either start declining or to have ouly modest increases when a certain density of plant population has been reached (Cavero *et al*., 2001). Also, planting at 80,000 plants ha^{-1} might have created a certain degree of artificial drought for the plants since soil water was in short supply under the dryland system. Furthermore, the observed reduction in total and marketable yields at Mugadza for the 80,000 plant population level in 2000/1 can be attributed to competition arising from high plant growth rate due to the high fertiliser rate (1000 kg ha^{-1} of ammonium nitrate) as well as rainfall. Under optimum conditions of rainfall and fertiliser, closely spaced plants compete for light and grow tall at the expense of reproductive development. Fruits on the tall plants were located higher up the plant canopy whilst for the shorter and sturdier plants, fruits were found at the lower strata of the plant canopy.

Marketable pepper fruit yield can respond quite differently to plant population increase as opposed to total fruit yield. Marketable fruit yield can increase with plant population in “Spanish” pepper (Jovicich *et al*., 2003), paprika type pepper (Kahn *et al*., 1997; Jovicich *et al*., 2004; Ogunlela and Koomen, 2005) and sweet pepper (Jovicich *et al*., 1999). In the present study, marketable fruit yield did not respond to plant population. A similar result was reported for bell pepper in Mississippi by Cushman and Horgan (2001). Apparently, marketable fruit yield was not as affected by competition as much as total fruit yield and that was why variation in plant population did not significantly influence marketable fruit yield. The higher fruit yield per plant at the lower plant population densities in the presence of lower numbers of fruits per plant can be explained by larger average fruit size at the lower plant population densities. Cavero *et al*., (2001) had reported slight decrease in weight per fruit in paprika as plant population increased; a result that was contradicted by the lack of response observed in our own study. Under such a situation, undesirable massive paprika plants with a higher rate of lodging can be produced (Kahn *et al*., 1997). Fruit yield or fruit number per plant generally decline as plant population increases. Sheldrick (2003) observed that higher plant densities can reduce fruit yield per plant in Jalapeno pepper. While fruit set per plant was said to decrease linearly as plant density increased in Spanish and bell pepper (Jovicich *et al*., 2003, 2004), fruit weight per plant and number of fruits per plant in egg plant (*Solanum gilo* L.) decreased with decreasing intra-row spacing (Aliyu *et al*., 1992) and both fruit yield per plant and fruit number per plant in different pepper types declined with increasing plant population (Cavero *et al*., 2001; Aliyu, 2002; Ogunlela and Koomen, 2005).

Double-row planting arrangement as opposed to the single-row arrangement was more beneficial to fruit yield and number as result of the better plant distribution, which meant a better light distribution within the plant canopy. The same explanation given for the result of fruit yield in the 2000/01 season is applicable in the 2001/02 season at Mugadza. The significant ($p<0.05$) increase in fruit yield observed for 80,000 plants ha^{-1} in 2001/02 can be attributed mainly to higher plant number since population did not affect fruit number per plant in that particular season. Plant growth was greatly reduced by moisture stress (data not shown) and there might have been less competition among plants as they were stunted in growth. However, the seasonal variation for the two years might have accounted for the lack of significant response of fruit yield per hectare and number of fruits per plant to differences in plant arrangement. These results suggest that the yield increase under a higher population in 2000/01 is attributable both to a higher plant population and higher fruit production per plant rather than fruit size. Whereas, paprika fruit yield increase in the 2001/02 season is attributable solely to higher number of plants per hectare as there were no significant differences in number of fruits per plant.

Under the 50,000 plants ha^{-1} plant population in the 2000/01 season, the single row planting had a little hedge over the double-row planting with respect to plant height possibly because there was greater plant competition for light than under the double-row arrangement, where better plant distribution minimized the competition for light. However, when plant population density reached the 80,000 plants ha^{-1} level, the advantage of a better plant distribution observed for the double-row arrangement at lower plant population was either lost or diminished. That would explain why paprika plants became taller when grown using the double-row arrangement under the highest plant population level. This is likely to predispose paprika plants to some degree of lodging, particularly if they fruit heavily. Sheldrick (2003) reported that growing Jalapeno pepper at higher plant densities resulted in taller plants with narrow branch angles. Such a plant canopy will allow a favourable distribution of light within it. Such high density planting will exclude the expense of thinning and also result in better competition with weeds.

A number of reasons have been deduced for the observed favourable responses of pepper fruit yield to increasing plant population. Lorenzo and Castilla (1995) observed that the higher Leaf Area Index (LAI) values in the higher bell pepper plant density treatment generated better radiation interception, which induced significantly higher total, commercial and first quality yields. Similarly, LAI values with increasing plant density in hot chili pepper at Samaru, Nigeria but leaf area ratio (LAR) values were lower at higher plant densities (Aliyu, 2002). Also, for bell pepper higher plant densities were said to have decreased absolute growth rates and that node number was the most important yield component contributing to plant density effects (Jollife and Gaye, 1995). Under greenhouse situation, pepper fruit yield and quality can be increased by managing shoot pruning and plant density (Jovicich *et al*., 1999).

Lack of significant response to treatment factors by the parameters measured at Kunyongana in the 2002/03 season can be explained in the drought that occurred during sensitive stages of growth. The treatments were not able to make their effects felt on the different parameters. The yield depression that occurred under high plant densities in the 2002/03 season was directly due to reduced plant numbers caused by high plant mortality. The high plant mortality was itself due to a combination of drought stress and soluble salt injury from the high rate of basal fertiliser (1,000 kg ha^{-1} of ammonium nitrate) under dryland conditions. It is also possible that evapotranspiration was higher under a situation where there were more plants. There was no response to plant population by average fruit weight in the present investigation. Similar result had been reported for bell pepper by Cushman and Horgan (2001) while Cavero *et al*. (2001) reported that weight per fruit in paprika pepper declined slightly with increase in plant population.

Increase in fruit yield with increasing plant population as observed in the present investigation is similar to results reported for once-harvested cayeune pepper (Decoteau and Graham, 1994); single machine-harvested Tabasco pepper (Sundstrom *et al*., 1984); multiple-harvested bell pepper (Stoffella and Bryan, 1988; Everett and Subramanya, 1983), Pepperoncini pepper (Motsenbocker, 1996), bell peppers (Jollife and Gaye, 1995) and paprika peppers (Kahn *et al*., 1997). In contrast, however, Cavero *et al*. (2001) reported that paprika fruit number per plant decreased as plant density increased from 13,333 to 500,000 plants ha^{-1}. Their finding may have been due to the fact that they used much higher plant populations than those in the present study. Locascio and Stall (1994) reported that in-row plant spacing affected bell pepper yield per plant, yield per plant being inversely related to plant population. Total fruit yield was higher with row arrangements under higher rather than lower plant populations. Batal and Smittle (1981) concluded that total plant population was a more important factor affecting bell pepper yield than plant arrangement while Sundstrom *et al.* (1984) noted that close spacing appeared to substantially reduce stem breakage. Their data suggested that adjacent plants in closely spaced treatments supported each other and avoided lodging.

Weather conditions were variable after transplanting as excessive dry and wet periods and high temperatures caused stress conditions during and after stand establishment. In 2000/01 the two sites (i.e., Mugadza and Masunda) were affected by drought, as there was no rains after transplanting resulting in seedling mortality. Fairly overgrown seedlings had to be transplanted from the nursery to replace missing plant stands in the field. At the Masunda site there were no follow-up rains after re-transplanting and establishment rates were therefore very low, hence the trial had to be abandoned before harvest data could be collected.

CONCLUSION

Increasing plant population from the current official recommendation of 55,000 plants ha^{-1} to above 65000 plants ha^{-1} is likely to give smallholder farmers higher total fruit yield in dryland paprika. There is need for further research to determine the upper limit for plant population, particularly on the basis of economic viability. Arranging plants in two rows per ridge rather than one row might give higher fruit yields per hectare and per plant.

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