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Contribution of subterranean clover (*Trifolium subterraneum*) to changes in morphological and physiological parameters raised alone and with birdsfoot trefoil (*Lotus corniculatus*)

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ABSTRACT

Changes in some morphological and physiological parameters (leaves/stems ratio, total plastid pigments content, fixed amount nitrogen) of birdsfoot trefoil (*Lotus corniculatus* L.) (cv. Targovishte 1) and three subterranean clover subspecies, i.e. *Trifolium subterraneum* ssp. *brachycalicinum* (cv. Antas), *Trifolium subterraneum* ssp. *yaninicum* (cv. Trikkala) and *Trifolium subterraneum* ssp. *subterraneum* (cv. Denmark) were studied in a field trial in the Institute of Forage Crops, Pleven, Bulgaria (2012-15). Crops were grown alone (100%) and in mixtures as follows: birdsfoot trefoil + *Trifolium subterraneum* ssp. *brachycalicinum* (50:50%); birdsfoot trefoil + *Trifolium subterraneum* ssp. *yaninicum* (50:50%); birdsfoot trefoil + *Trifolium subterraneum* ssp. *subterraneum* (50:50%). Leaves/stems ratio for alone grown crops was found: birdsfoot trefoil (1.33), *Trifolium subterraneum* ssp. *brachycalicinum* (1.02), *Trifolium subterraneum* ssp. *yaninicum* (0.93) and *Trifolium subterraneum* ssp. *subterraneum* (0.93). Leaves/stems ratio for birdsfoot trefoil in all mixtures was found be higher as compared to alone grown birdsfoot trefoil - by 13.0% for the mixture with *Trifolium subterraneum* ssp. *yaninicum*, by 16.3% for that with *Trifolium subterraneum* ssp. *brachycalicinum* and by 20.1% for the mixture with *Trifolium subterraneum* ssp. *subterraneum*. Total plastid pigments in birdsfoot trefoil increased in all mixtures: with *Trifolium subterraneum* ssp. *brachycalicinum* by 7.4%, with *Trifolium subterraneum* ssp. *subterraneum* by 8.1% and with *Trifolium subterraneum* ssp. *yaninicum* by 15.6%. From mixtures of birdsfoot trefoil were obtained more fixed amount of nitrogen - from 1.71 kg N/da (with *Trifolium subterraneum* ssp. *subterraneum*) to 4.84 kg N/da (with *Trifolium subterraneum* ssp. *brachycalicinum*) as compared to alone grown birdsfoot trefoil. Birdsfoot trefoil and subterranean clover in mixtures showed good tolerance, morphological and physiological status.

Key words: Birdsfoot trefoil, Leaves stems ratio, Mixtures, Plastid pigments, Subterranean clover

Interest towards intercropped systems is rising in recent years due to their role in formation of a system for sustainable agriculture (Luscher *et al*. 2014, Kusvuran *et al.* 2014). They are more effective than pure grown in using environmental resources, better withstand adverse conditions and are more productive (Porqueddu *et al.* 2003, Chourkova 2014). The components in mixtures go into competitive relations and many morphological and physiological parameters change. The leaves/stems ratio is an important morphological characteristic and indicator for quality and uptake of the forage (Buxton *et al*. 1985). From the physiological status of components depends on the productivity of mixtures.

Due to the nitrogen fixation in mixtures with participation of legumes, the nitrogen content increased and nitrogen obtained in this way is used directly by the plants (Peeters *et al.* 2006). In the present study birdsfoot trefoil is included - traditional nitrogen fixing forage crop that is accepted by all kinds of animals and does not cause swelling under grazing (Vučković 2004, Stevanovic *et al.* 2015).

Subterranean clover (*Trifolium subterraneum* L.) is a widespread component in the pastures and other grasslands of the temperate areas of Central and Northern Europe and America (Nichols *et al.* 2012). Investigations on subterranean clover as a component of sown pasture in recent years have shown that it has practical application for local climatic conditions in Bulgaria (Vasilev 2006, Vasileva and Vasilev 2012, Ilieva *et al.* 2015).

The aim of this work was to study changes in some morphological and physiological parameters - leaves/stems ratio, total plastid pigments content (chlorophylls and carotenoids) and amount of fixed nitrogen in the plants of birdsfoot trefoil and subterranean clover grown pure and in mixtures with direction of use for forage.

MATERIALS AND METHODS

The trial was conducted at the experimental field (43° 23’N, 24º 34’E, 230 m altitude) of the Institute of Forage Crops, Pleven, Bulgaria (2012-15) on podzolized soil

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subtype without irrigation. Long plot method was used with size of plots 70 m^2 (1.40 × 50 m) four replicated. The object of study were birdsfoot trefoil (*Lotus corniculatus* L.) cv. Targovishte 1 and three subclover subspecies, i.e. *Trifolium subterraneum* ssp. *brachycalicinum* (cv. Antas), *Trifolium subterraneum* ssp. *yaninicum* (cv. Trikkala) and *Trifolium subterraneum* ssp. *subterraneum* (cv. Denmark), grown pure (100%) and in mixtures in ratios birdsfoot trefoil: subterranean clover (50:50%), as follows: birdsfoot trefoil + *Trifolium subterraneum* ssp. *brachycalicinum* (50:50%); birdsfoot trefoil + *Trifoilium subterraneum* ssp. *yaninicum* (50:50%); birdsfoot trefoil + *Trifolium subterraneum* ssp. *subterraneum* (50:50%). The sowing was done in autumn (beginning of October) of 2012 with sowing rates for birdsfoot trefoil 1.5 kg/da and for subterranean clover 2.5 kg/da, between row space was 11.5 cm. Sowing rate in mixtures was 1/2 from this for pure swards. No fertilizers and pesticides were applied during the vegetation.

The swards were harvested for forage. Two cuts were obtained during the first and second year after sowing (2013 and 2014) and one cut during the third (2015). At each harvest, samples were taken from an area of 0.25 m^2, divided are the leaves and stems, and weighted separately (g fresh weight). The leaves/stems ratio was calculated (individually and in mixtures).

In fresh plant samples during the three years total plastid pigments content (chlorophyll a, chlorophyll b, and carotenoids) (mg/100 g FW) was determined according Zelenskii and Mogileva (1980). For the mixtures samples were taken from every component.

The Carlsson and Huss-Danell (2003) formulae for roughly determine the amount of fixed nitrogen in the field conditions was calculated in the swards of birdsfoot trefoil grown pure and in mixtures with subterranean clover (kg N/da). The data were averaged and processed statistically using SPSS software (2012).

RESULTS AND DISCUSSION

Agrometeorological conditions in the first year after sowing were unfavourable to the development of crops. Small quantities and unevenly distributed rainfall in May initiated the early spring drought lasting one month. The period was accompanied by monthly average temperatures with values above normal for the area. Evenly distributed rainfall are from the second half of May and in June. After the first decade of July comes drought lasted and in August and September (82 days). These adverse conditions troubled the growth and development of plants.

The second and third years of vegetation were more favourable. The average annual temperature in the second year was with higher values (13.2°C), without extremely high temperatures as well prolonged drought periods and in the third year the amount of rainfall (856.8 l/m^2) was greatest.

These conditions impacted on the overall development of birdsfoot trefoil and subterranean clover. Important morphological characteristic object in the current study is the leaves/stems ratio. It is related to the quality and acceptance of the forage (Cohen 2001, Soster *et al.* 2004). Data show that the leaves/stems ratio in birdsfoot trefoil (alone and in mixtures) during the first year after sowing was with the lowest values (1.08) (Table 1). This is understandable, due to adverse agro meteorological conditions, as well as the age of the crop. In mixtures with subterranean clover values were higher than pure grown birdsfoot trefoil - from 13.1% for the mixture with *Trifolium subterraneum* ssp. *yaninicum* (1.23) to 34.9% for the mixture with *Trifolium subterraneum* ssp. *subterraneum* (1.46). *Trifolium subterraneum* ssp. *subterraneum* is subspecies clover, which is small in size leaves less competitive compared to the other two subspecies, lower as well, which has an impact on the development of the accompanying component (birdsfoot trefoil). Pecetti and Piano (1998) found that the size of the leaves is essential for the competitiveness of subterranean clover in mixtures. Competition for basic nutrients, as well as factors of the environment, such as light, heat ect. in a mixture with *Trifolium subterraneum.* ssp. *subterraneum* was smaller. Because of this the deviation in value was so high.

The leaves/stems ratio in subterranean clover in pure swards varied in narrow limits and the lowest was found in *Trifolium subterraneum* ssp. *subterraneum*. In mixtures the differences were similar for *Trifolium subterraneum* ssp. *brachycalicinum* and *Trifolium subterraneum* ssp. *yaninicum*. Cohen (2001) found a directly proportional relationship between the leaves/stems ratio and protein

Table 1 Leaves/stems ratio in birdsfoot trefoil and subterranean clover pure grown and in mixtures

Treatments	2013	2014	2015
Birdsfoot trefoil (100%)	1.08±0.34	1.49±1.63	1.41±1.43
Birdsfoot trefoil +	1.28±1.27	1.74±0.89	1.62±0.81
Tr. subterr. ssp. *brachycalicinum*	1.10±0.31	1.26±1.86	1.17±1.20
Birdsfoot trefoil +	1.23±0.24	1.67±2.27	1.61±2.14
Tr. subterr. ssp. *yaninicum*	0.99±0.01	1.05±0.26	1.00±0.02
Birdsfoot trefoil +	1.46±1.29	1.77±3.71	1.56±2.78
Tr. subterr. ssp. *subterraneum*	0.89±0.02	1.09±0.16	1.11±0.21
Tr. subterr. ssp. *brachycalicinum* (100%)	0.99±0.07	1.07±0.39	1.01±0.08
Tri. subterr. ssp. *yaninicum* (100%)	0.90±0.45	0.93±0.34	0.95±0.25
Tr. subterr. ssp. *subterraneum* (100%)	0.85±0.54	0.96±0.80	0.99±0.32
SE (P=0.05) for birdsfoot trefoil	0.07	0.06	0.04
SE (P=0.05) for subterranean clover	0.03	0.05	0.04
±SD for birdsfoot trefoil	0.15	0.12	0.09
±SD for subterranean clover	0.08	0.11	0.08

content in subterranean clover and consider this ratio as an important indicator of the forage quality.

In the second year the leaves/stems ratio in birdsfoot trefoil in mixtures was higher than that in pure sward - from 11.6% for the mixture with *Trifolium subterraneum* ssp *yaninicum* (1.67) to 18.6% for mixtures with *Trifolium subterraneum* ssp. *subterraneum* (1.77). Similar were the increases for subterranean clover as well (12.9%-18.5%). The leaves/stems ratio in birdsfoot trefoil in the last experimental year varied in narrow limits (1.56-1.62).

Notice that, in mixtures of birdsfoot trefoil with subterranean clover the leaves/stems ratio values were higher than its value in pure swards. The higher leaves/stems ratio determines a higher quality and intake of forage and this was found by many authors (Frame *et al.* 1998, Smart *et al.* 1998, Cohen 2001). Improving the leaves/stems ratio in birdsfoot trefoil would have practical significance for increasing quality and preference of the animals to forage.

Data for the leaves/stems ratio on average for the period (Fig 1) showed that in pure grown birdsfoot trefoil it was 1.33. Our results are in agreement with these of Soster *et al.* (2004) and Ducati *et al.* (2015), who have determined some agronomical characteristics in this crop and found leaves/stems ratio with values 1.40. Ayres *et al.* (2008) found higher values ranged from 1.47 to 1.68.

Leaves/stems ratio in birdsfoot trefoil in mixtures with subterranean clover varied between 1.50 to 1.60. In the three mixtures with subterranean clover the leaves/stems ratio was higher than in pure birsdfoot trefoil - by 13.0% for mixtures with *Trifolium subterraneum* ssp. *yaninicum,* by 16.3% for this with *Trifolium subterraneum* ssp. *brachycalicinum* and by 20.1% for mixtures with *Trifolium subterraneum* ssp. *subterraneum.*

During the first experimental year total plastid pigments content was lowest due to the age of the sward as well agro meteorological conditions (Table 2). In mixtures of birdsfoot trefoil with *Trifolium subterraneum* ssp. *subterraneum*

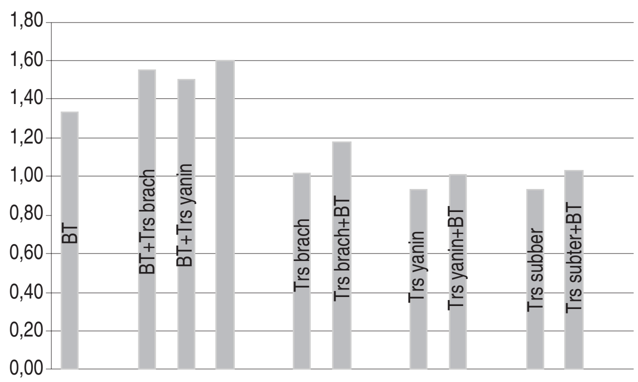

Fig 1 Leaves/stems ratio in birdsfoot trefoil and subterranean clover pure grown and in mixtures (average for the period). BT - Birdsfoot trefoil; Trs brach - *Tr. subterraneum* ssp. *brachycalicinum; Trs yanin - Tr. subterraneum* ssp. *yaninicum; Trs subter - Tr. subterraneum* ssp. *Subterraneum.* (for birdsfoot trefoil, ±SD=0.11, SE (P=0.05)=0.05; for subterranean clover, ±SD=0.10, SE (P=0.05)=0.04

Table 2 Total plastid pigments content in birdsfoot trefoil and subterranean clover pure grown and in mixtures (mg/100 g FW)

Treatments	2013	2014	2015
Birdsfoot trefoil (100%)	213.22	279,78	230.16
Birdsfoot trefoil +	285.86	265.14	331.23
Tr. subterr. ssp. *brachycalicinum*	273.00	317.64	373.35
Birdsfoot trefoil +	267.49	324.96	336.09
Tr. subterr. ssp. *yaninicum*	252.07	226.71	297.93
Birdsfoot trefoil +	263.91	284.43	358.98
Tr. subterr. ssp. *subterraneum*	298.24	250.51	287.22
Tr. subterr. ssp. *brachycalicinum* (100%)	294.57	345.03	335.55
Tri. subterr. ssp. *yaninicum* (100%)	251.52	280.99	249.51
Tr. subterr. ssp. *subterraneum* (100%)	285.43	315.45	465.36
SE (P=0.05) for birdsfoot trefoil	17.39	13.00	15.87
SE (P=0.05) for subterranean clover	4.91	11.82	20.81
±SD for birdsfoot trefoil	34.78	26.00	31.75
±SD for subterranean clover	12.03	28.96	50.99

total plastid pigments content was found increased in the two components (for birdsfoot trefoil by 18.0% and for subterranean clover by 6.7%, respectively). The tendency was analogue for the mixture with *Trifolium subterraneum* ssp. *yaninicum* (for birdsfoot trefoil by 39.9% and for subterranean clover by 7.9%). In mixture of birdsfoot trefoil with *Trifolium subterraneum* ssp. *brachycalicinum,* total plastid pigments content in birdsfoot trefoil increased by 18.2% and in subterranean clover decreased by 7.7%.

Total plastid pigments content in the second experimental year remains almost unchanged in the mixture of birdsfoot trefoil with *Trifolium subterraneum* ssp. *subterraneum* for both components as compared pure grown crops. In the other two mixtures plastid pigments content in birdsfoot trefoil decreased to 19.0% and in subterranean clovers increased to 8.6%.

Significant increases in the values of this indicator in the components of mixtures as compared to these of pure grown crops were reported in the last experimental year. Total plastid pigments content in all mixtures in birdsfoot trefoil increased (from 8.4 to 29.4%). Total plastid pigments content in subterranean clover increased in *Trifolium subterraneum* ssp. *subterraneum* by 38.5% and in *Trifolium subterraneum* ssp. *brachycalicinum* by 8.4%, and decreased in *Trifolium subterraneum* ssp. *yaninicum* by 10.1%. Total plastid pigments content in two components increased in mixtures of birdsfoot trefoil with *Trifolium subterraneum* ssp. *brachycalicinum* and with *Trifolium subterraneum* ssp. *subterraneum*.

For the period of the study a greater increase in the values of the total plastid pigments content in mixtures as compared to pure grown crops was recorded in birdsfoot

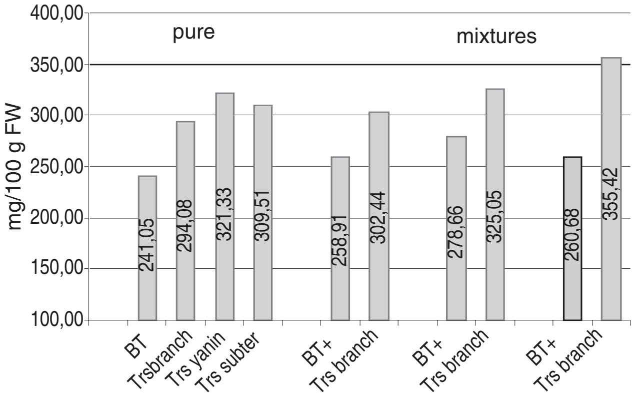

Fig 2 Total plastid pigments content in birdsfoot trefoil and subterranean clover pure grown and in mixtures (mg/100 g FW) (average for the period of study). BT - Birdsfoot trefoil; Trs brach - *Tr. subterraneum* ssp. *brachycalicinum; Trs yanin* - *Tr. subterraneum* ssp. *yaninicum; Trs subter* - *Tr. subterraneum* ssp. *Subterraneum.* (for birdsfoot trefoil, ±SD=15.37, SE (P=0.05)=7.68; for subterranean clover, ±SD=8.84, SE (P=0.05)=21.66)

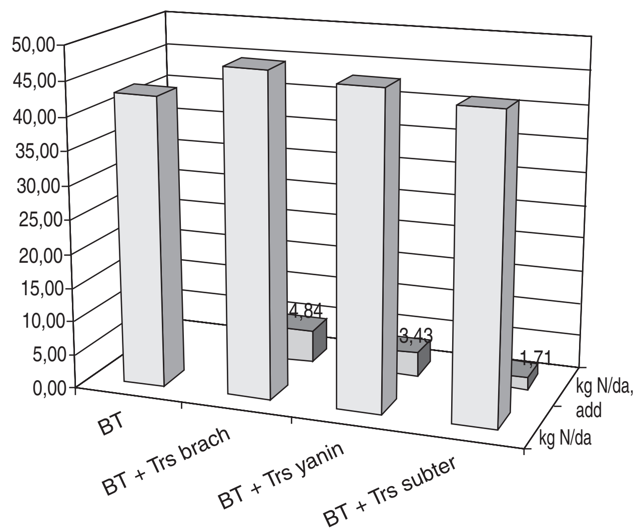

Fig 3 Amount of fixed nitrogen from birdsfoot trefoil pure grown and in mixtures with subterranean clover for three years period. BT - Birdsfoot trefoil; Trs brach - *Tr. subterr.* ssp. *brachycalicinum; Trs yanin - Tr. subterr.* ssp. *yaninicum; Trs subter - Tr. subterr.* ssp. *subterraneum* (±SD=2.09, SE (P=0.05)=1.04)

trefoil. Data on average for the period (Fig 2) show this trend. Total plastid pigments content in birdsfoot trefoil was 241.05 mg/100 g FW, but in subterranean clover varied from 294.08 mg/100 g FW to 321.33 mg/100 g FW. Total plastid pigments content in mixtures changes in both components. So, in birdsfoot trefoil it increased from 7.4 to 15.6%. In subterranean clover total plastid pigments content significant increased only in *Trifolium subterraneum* ssp. *subterraneum* – by 14.8%.

Total plastid pigments content significantly increased in both components of mixtures of birdsfoot trefoil (by 8.1%) with *Trifolium subterraneum* ssp. *subterraneum* (by 14.8%). These data correspond to the change in the leaves/stems ratio, the coefficient of correlation between leaves/stems ratio and total plastid pigments is r = 0.60.

The amount of fixed nitrogen in the mixtures changes and depends on the competition between the components. There were amount of fixed nitrogen from 1.71 N/da (birdsfoot trefoil + *Trifolium subterraneum* ssp. *subterraneum*) to 4.84 kg N/da (birdsfoot trefoil + *Trifolium subterraneum* ssp. *brachycalicinum*) more as compared to the amount obtained by pure grown birdsfoot trefoil (Fig 3). Competition for soil nitrogen mixtures may have a beneficial effect on nitrogen fixing process as in the case birdsfoot trefoil and subterranean clover have the same type of nitrogen exchange. They fix nitrogen from the atmosphere through nitrogenaze in the nodules.

Changes in the morphological and physiological parameters of the crops studied are associated with the metabolic role of nodules, which are strong acceptor of carbon asimilates from leaves, but are simultaneously and donor of organic nitrogen for leaves, mainly in the form of transport amino acids and amides (Atkins *et al.* 1986).

Leaves/stems ratio for pure grown birdsfoot trefoil (1.33), *Trifolium subterraneum* ssp. *brachycalicinum* (1.02), *Trifolium subterraneum* ssp. *yaninicum* (0.93) and *Trifolium subterraneum* ssp. *subterraneum* (0.93) was found.

Leaves/stems ratio for birdsfoot trefoil in all mixtures was found be higher as compared to pure grown birdsfoot trefoil - by 13.0% for the mixture with *Trifolium subterraneum* ssp. *yaninicum*, by 16.3% for that with *Trifolium subterraneum* ssp. *brachycalicinum* and by 20.1% for the mixture with *Trifolium subterraneum* ssp. *subterraneum*.

Total plastid pigments content in birdsfoot trefoil increased in all mixtures tested: with *Trifolium subterraneum* ssp. *brachycalicinum* by 7.4%, with *Trifolium subterraneum* ssp. *subterraneum* by 8.1% and with *Trifolium subterraneum* ssp. *yaninicum* by 15.6%. Total plastid pigments content in subterranean clover was found increased only for *Trifolium subterraneum* ssp. *subterraneum* (by 14.8%).

From mixtures of birdsfoot trefoil were obtained more fixed amount of nitrogen - from 1.71 kg N/da (with *Trifolium subterraneum* ssp. *subterraneum*) to 4.84 kg N/da (with *Trifolium subterraneum* ssp. *brachycalicinum*) as compared to pure grown birdsfoot trefoil. Birdsfoot trefoil and subterranean clover in mixtures showed good tolerance, morphological and physiological status.

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Yield, economics, nutrient uptake and quality of coriander (*Coriandrum sativum*) under different sowing time, varieties and plant growth regulators

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ABSTRACT

A field experiment was carried out in *rabi* seasons of 2011-12 and 2012-13 at Agronomy Farm, S.K.N. College of Agriculture, Jobner (Rajasthan), to assess the effect of sowing time and plant growth regulators on yield, economics, nutrient uptake and quality of coriander (*Coriandrum sativum* L.) varieties grown under irrigated loamy sand soil of semi-arid eastern plain zone of Rajasthan. The experiment consisting of two sowing times, viz. normal (1st week of November) and late (3rd week of November), three varieties, viz. RCr-41, RCr-435 and RCr-480 and five plant growth regulators treatments (PGRs), viz. triacontanol @ 1 000 ppm, brassinolide @ 1.0 ppm, thiourea @ 1 000 ppm and NAA @ 50 ppm, including one control (water sprayed) treatment were replicated thrice in split-plot design. The 2-year results revealed that the normal sown coriander crop produced significantly higher seed (by 31%) and stover yields, total N and P uptake (by 20 and 25%), per-day productivity (by 17%) and net returns (by 59%), partial factor productivity (PFP), nutrient harvest index (NHI), protein (by 21%) and oil (by 41%) yields compared to late sown crop. However, late sown crop resulted significantly higher nitrogen content in seed and stover and protein content in seed over normal sown. Among 3-varieties, RCr-480 produced significantly higher yields (15%), total N (15%) and P (by 14%) uptake, per-day productivity(by 14%) and net returns (by 34%), essential oil (by 21%) and protein (17%) yields, PFP-NP and NHI-NP during both the years as compared to RCr-41, which were statistically at par with RCr-435, except oil yield, NHI-NP in second year. The foliar spray of PGRs significantly enhanced the yields (by 10-22%), nutrient content and uptake and quality of coriander over water spray. The highest seed and stover yields, N and P uptake, per-day productivity and net returns, protein and oil yield and PFP-NP with 1 000 ppm triacontanol, over control, 50 ppm NAA and 1 000 ppm thiourea, and remained statistically at par with 1.0 ppm brassinolide, except per-day-net returns and oil yield. Overall, our results suggest that adoption of RCr-480 variety under normal sown condition with 1 000 ppm triacontanol spray can enhance crop productivity, profitability, nutrient uptake and quality of coriander in semi-arid region of India and elsewhere under similar agro-climatic conditions.

Key words: Coriander, Nutrient uptake, Partial factor productivity, Plant growth regulators, Profitability

Coriander (*Coriandrum sativum* L.) is one of the oldest seed spices most widely used by the mankind as condiment. The green leaves and fruits of coriander have a pleasant aromatic odour due to presence of 'coriandrol'. Good quality oleoresin has extracted from coriander seed which can be used for flavouring beverages, sweets, pickles, sausages, snacks, etc. The research findings across the country conclusively revealed negative impact of delayed sowing on yield, nutrient content and uptake and quality of seed especially on test weight but the extent of reduction depends upon the prevailing weather conditions. A late sown crop produces shrivelled grains as well as poor quality compared to early sowing leading to low yield.

Selection of proper improved variety as per the growing conditions is another way to improve the productivity and quality of the crop. All the three (RCr-41, RCr-435 and RCr-480) varieties are suitable for normal conditions and covers a large area of state but yield stagnation has been reported prevailing management practices. Therefore, it was felt necessary to enhance the productivity of coriander through alternative practices like use of PGRs. Use of triacontanol, brassinolide, thiourea and NAA based PGRs has been reported to induce physiological efficiencies including photosynthetic ability of plants (Jain *et al.* 1988, Sarada *et al.* 2008), growth promoting activity (Mandava 1988), also improve the resistance in plant against the water, salinity, low and high temperature stresses (Rao *et al.* 2002), improve the dry matter partitioning and subsequently enhance the

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productivity of crops and may mitigate the problem of late sowing to bring marked biological activity in plants (Sahu and Solanki 1991). Thus, for achieving the attainable yield potential with good quality of the crop the optimum time of sowing, adoption of most suitable varieties and application of plant growth regulators are essentially required. So keeping in view the above facts, the present investigation has been planned to evaluate the effect of sowing times, varieties and plant growth regulators on yield, economics, nutrient uptake and quality of coriander.

MATERIALS AND METHODS

A field experiment was conducted for two consecutive years in *rabi* seasons of 2011-12 and 2012-13 at the Agronomy Farm, S K N College of Agriculture, Jobner, situated at 27° 05' N latitude, 75° 28' E longitude and at an altitude of 427 AMSL in Jaipur district of Rajasthan. This region is categorized as semi-arid eastern plain zone of Rajasthan. The soil of the experimental site was loamy sand in texture with low in organic carbon (0.16%) and available nitrogen (126.5 kg/ha), medium in available phosphorus (16.7 kg/ha) and potassium (171.9 kg/ha) and alkaline in reaction with pH 8.3. The experiment consisting of two sowing times viz., normal (1^{st} week of November) and late (3^{rd} week of November), 3-varieties, viz. RCr-41, RCr-435 and RCr-480 as main plot treatments and five treatments of plant growth regulators viz., triacontanol @ 1 000 ppm, brassinolide @ 1.0 ppm, thiourea @ 1 000 ppm and NAA @ 50 ppm including control (water sprayed) as sub-plot treatment, total 30 treatment combinations were replicated thrice in split plot design. Before sowing coriander varieties seed was treated with bavistin @ 2 g/kg of seed. The crop was sown in rows at 30 cm apart and 2-3 cm depth with a seed rate of 12 kg/ha as per treatments under normal and late sown conditions. A uniform dose of 60 kg N, 40 kg P_2O_5 and 20 kg K_2O/ha was applied in all plots. Entire quantity of P and K and half dose of N were applied at the time of sowing and the remaining nitrogen was applied in two equal splits with third and fourth irrigations. Two foliar spray of triacontanol @ 1 000 ppm, brassinolide @ 1.0 ppm, thiourea @ 1 000 ppm and NAA @ 50 ppm were done at 40 and 70 days after sowing. The spray volume was 400 and 600 litres/ha for application at 40 and 70 DAS, respectively.

Coriander was sown on 4^{th} and 1^{st} November (under normal condition) and 19^{th} and 16^{th} November (under late sown condition) in 2011 and 2012, respectively, and the crop was harvested on 22 and 21 March during 2012 and 2013, respectively. The plant samples were collected at harvest and dried in oven (±70°C), processed and thoroughly mixed and analyzed for estimation of nitrogen, phosphorus and essential oil content was by Kjeldahl, Vanado-molybdate yellow colour and Clevenger apparatus, respectively. N and P uptake were calculated by formula (Nutrient content/100 multiplied by seed/stover yield in kg/ha). The estimated values of different nutrient use indices viz; partial factor productivity (PFP), and harvest index (HI) of applied N and P were computed by using the formulas as suggested by Fageria and Baligar (2003) and Dobermann (2005) which are as follows:

Partial factor productivity of applied nutrient (PFP) $= Y_t / N_a$

Nutrient harvest index (%) $= N_s / N_t \times 100$

where, Y_t = Yield under treatment plots (kg/ha); N_a = Amount of nutrient added (kg/ha); N_s = Nutrient uptake by seed at harvest; N_t = Nutrient uptake by whole plant (seed + stover) at harvest.

Yield, nutrient uptake and quality parameters were measured as per standard procedures. Economics was calculated based on prevailing cost of input and output in local market. All the data were statistically analyzed using the analysis of variance (ANOVA) techniques (Gomez and Gomez 1984). The critical difference at 0.05% level probability were calculated to assess the significance between treatments.

RESULTS AND DISCUSSION

Effect of sowing time

The sowing times significantly influenced the yield, economics, nutrient content and uptake and quality parameters of coriander. Normal sown crop resulted significantly higher seed (1456 and 1501 kg/ha) and stover (2 150 and 2 221 kg/ha) yields (Table 1), productivity (10.40 and 10.65 kg/day/ha) and net returns (₹ 228 and 239/day/ha) in 2011-12 and 2012-13 over late sown crop, respectively (Table 2).

It is an established fact that sinks capacity largely governs crop productivity (Evans 1975). This might be due to favourable environmental conditions available to the crop during its initial growth, flowering and fruiting stages. The possible reason for low yield in delayed sowing might be due to availability of insufficient time for vegetative growth as the plant entered the reproductive phase at a faster rate. These results are in conformity with the findings of Meena *et al.* (2006) and Bhadkariya *et al.* (2007).

The similar results were observed in total (seed + stover) N (62.5 and 66.5 kg/ha) and P (13.2 and 14.3) uptake (Fig 1 and 2) as well as uptake in seed and stover individually, total NP-PFP (14.56 and 15.01) and NHI of (65.0 and 64.6%) as well as individual nutrient PFP and NHI was significantly higher with normal sown crop compared to late sown crop in 201-12 and 2012-13, except NHI-N and NHI-NP in 2011-12, respectively (Table 1, 2 and 3). However, N content in seed and N and P content in stover were significantly higher with late sown crop during both the years. Therefore, the nitrogen content in both seed and stover followed a reverse trend to that of seed and stover yield. A decreased nitrogen content under normal sown crop could be due to the dilution effect by higher yield. The increased nitrogen and phosphorus uptake under normal sown crop could be ascribed due to higher total biomass production. Thus, significant improvement in seed and stover yield by virtue of higher photosynthesis under normal sown crop ultimately resulted in higher uptake of nitrogen and

Table 1 Effect of sowing time, varieties and plant growth regulators on yields, nitrogen content and uptake in seed and stover of coriander

Treatment	Seed yield (kg/ha)		Stover yield (kg/ha)		N content (%)				N uptake (kg/ha)			
					Seed		Stover		Seed		Stover	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Sowing time												
Normal	1456	1501	2150	2221	2.84	2.92	0.969	1.005	41.5	44.0	21.0	22.5
Late	1106	1143	1735	1807	3.09	3.16	1.026	1.065	34.3	36.2	17.6	19.0
SEm±	22	21	33	32	0.04	0.03	0.012	0.011	0.44	0.42	0.22	0.22
CD (P=0.05)	69	66	104	100	0.11	0.10	0.037	0.035	1.37	1.31	0.70	0.68
Varieties												
RCr-41	1179	1217	1853	1921	2.90	2.98	0.979	1.017	34.1	36.2	17.8	19.2
RCr-435	1316	1356	1998	2069	3.02	3.08	1.012	1.050	39.6	41.7	20.1	21.6
RCr-480	1347	1393	1976	2053	2.98	3.06	1.003	1.038	40.0	42.5	19.9	21.4
SEm±	27	26	40	39	0.04	0.04	0.014	0.014	0.53	0.51	0.27	0.27
CD (P=0.05)	85	81	127	123	NS	NS	NS	NS	1.68	1.61	0.86	0.83
Plant growth regulators												
Control	1128	1178	1733	1825	2.66	2.72	0.918	0.952	29.9	31.9	15.8	17.3
Tricontanol @ 1000 ppm	1380	1421	2061	2152	2.97	3.06	1.009	1.048	40.8	43.3	21.2	22.4
Brassinolide @ 1 ppm	1365	1398	2109	2107	3.06	3.13	1.020	1.058	41.6	43.6	20.7	22.1
Thiourea @ 1000 ppm	1273	1315	1949	2052	3.11	3.19	1.029	1.067	39.4	41.8	20.1	21.8
NAA @ 50 ppm	1258	1298	1860	1935	3.03	3.10	1.012	1.050	37.9	40.1	18.7	20.2
SEm±	24	25	37	38	0.05	0.04	0.015	0.015	0.56	0.54	0.29	0.28
CD (P=0.05)	69	70	104	106	0.13	0.12	0.043	0.042	1.60	1.54	0.81	0.79

Table 2 Effect of sowing time, varieties and plant growth regulators on phosphorus content and uptake in seed and stover, per day productivity and net returns of coriander

Treatments	P content (%)				P uptake (kg/ha)				Productivity/ day (kg/ha)		Net returns/day (Rs/ha)	
	Seed		Stover		Seed		Stover					
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Sowing time												
Normal	0.530	0.550	0.253	0.269	7.73	8.27	5.48	6.02	10.40	10.65	228	239
Late	0.538	0.560	0.269	0.283	5.96	6.41	4.60	5.03	8.85	9.07	143	154
SEm+	0.007	0.006	0.003	0.003	0.10	0.09	0.06	0.06	0.16	0.15	3	3
CD (P=0.05)	NS	NS	0.010	0.011	0.31	0.28	0.19	0.18	0.50	0.48	11	10
Varieties												
RCr-41	0.525	0.548	0.256	0.273	6.19	6.66	4.66	5.16	8.86	9.08	155	165
RCr-435	0.540	0.560	0.265	0.279	7.11	7.59	5.27	5.75	9.89	10.11	196	207
RCr-480	0.537	0.558	0.261	0.275	7.24	7.77	5.18	5.67	10.12	10.39	206	218
SEm+	0.009	0.007	0.004	0.004	0.12	0.11	0.07	0.07	0.20	0.19	4	4
CD (P=0.05)	NS	NS	NS	NS	0.38	0.35	0.23	0.22	0.62	0.59	13	13
Plant Growth Regulators												
Control	0.513	0.534	0.248	0.261	5.78	6.29	4.27	4.73	8.47	8.78	149	163
Tricontanol @ 1000ppm	0.538	0.559	0.262	0.277	7.42	7.94	5.50	5.92	10.37	10.60	218	228
Brassinolide @ 1 ppm	0.545	0.565	0.268	0.284	7.44	7.89	5.43	5.94	10.26	10.43	186	195
Thiourea @ 1000 ppm	0.540	0.562	0.266	0.281	6.87	7.39	5.20	5.73	9.56	9.81	190	201
NAA @ 50 ppm	0.534	0.555	0.259	0.276	6.72	7.20	4.79	5.31	9.45	9.68	185	196
SEm+	0.008	0.008	0.004	0.004	0.11	0.10	0.07	0.07	0.18	0.18	4	4
CD (P=0.05)	0.024	0.022	0.011	0.011	0.31	0.28	0.21	0.21	0.52	0.52	10	11

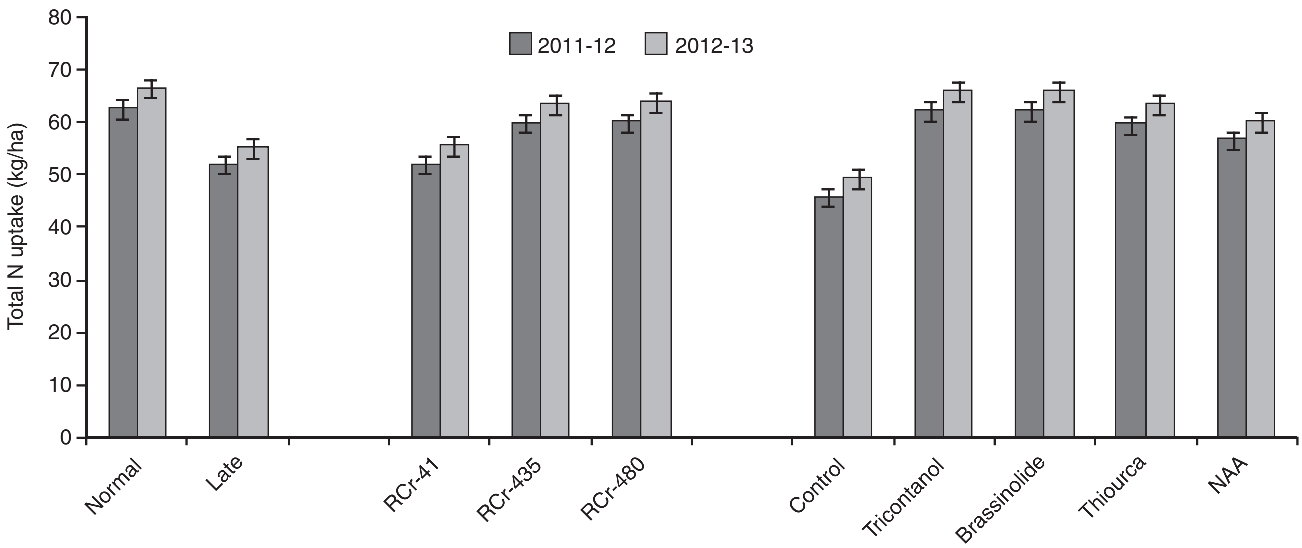

Fig 1 Effect of sowing time, varieties and plant growth regulators on total N uptake by coriander

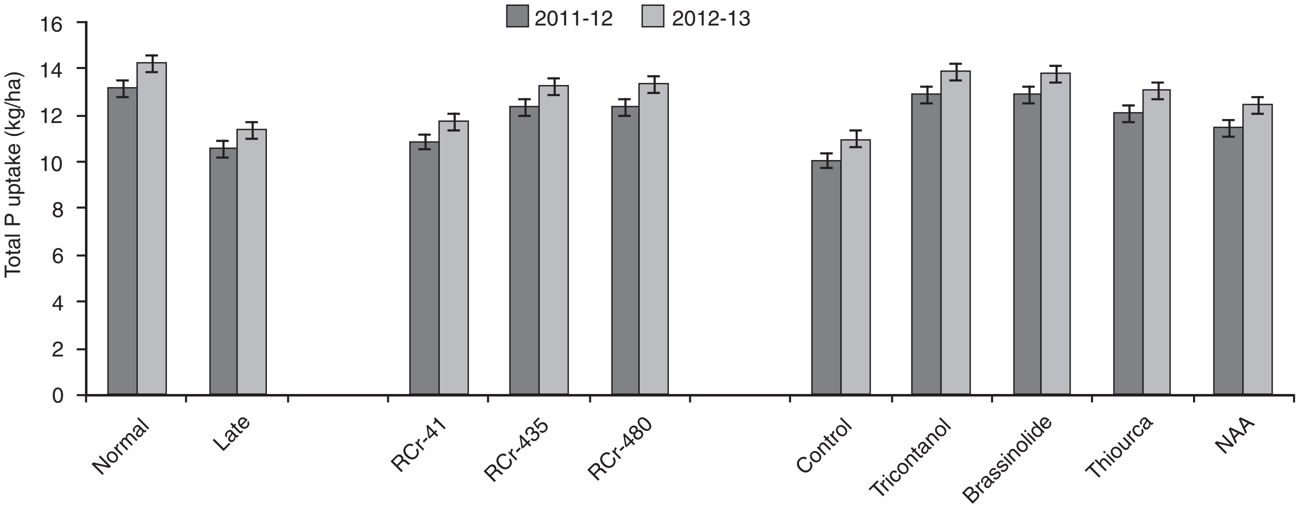

Fig 2 Effect of sowing time, varieties and plant growth regulators on total P uptake by coriander

phosphorus over late sown crop.

Quality parameters (protein and essential oil content in seed) of coriander were also significantly influenced with sowing times (Table 4). The significantly higher protein yield (260 and 275 kg/ha), oil yield (5.58 and 5.96 kg/ha) and essential oil content in seed were observed with normal sown crop as compared to late sown crop, while significantly higher protein content in seed was recorded with late sowing during both years, respectively. The reason could be traced back in temperature mediated effects on plants physiological processes and adequate absorption of nutrients. These findings are in close conformity with the findings of Balai and Keshwa (2011).

Effect of varieties

Coriander varieties performed differentially due to agronomic management and application of PGRs. RCr-480 recorded significantly higher seed (1 347 and 1 393 kg/ha), stover (1 976 and 2 053 kg/ha) yields (Table 1), crop productivity (10.12 and 10.39 kg/day/ha) and net returns (₹ 206 and 218/day/ha) compared to RCr-41 and being at par with RCr-435 during 2011-12 and 2012-13, respectively. The RCr-480 variety resulted in average (mean of 2-year) increase of 14, 7, 14 and 33% in seed yield, stover yield, per-day-productivity and net returns over RCr-41. Thus, the improvement in above these regulative processes of coriander evidenced from higher biomass and nutrients accumulation in RCr-480 and RCr-435 varieties over RCr-41. The marked variation in yield and economics of these varieties RCr-480, RCr-435 and RCr-41 were also observed under multi-location trials conducted under AICRP on spices (AICRPS, 2011 and Balai and Keshwa 2010).

Nutrient uptake and quality of coriander seed were also significantly differed in all the 3-varieties (Table 1, 2 and 3). However, the N and P content in seed and stover of all the verities remained statistically at par. Total uptake of N (59.9 and 63.9 kg/ha) and P (12.4 and 13.4 kg/ha) (Fig 1 and 2) as well as individual N and P uptake by seed and stover,

Table 3 Effect of sowing time, varieties and plant growth regulators on partial factor productivity (PFP) and nutrient harvest index (NHI) of nitrogen and phosphorous in coriander

Treatment	PFP-N		PFP-P		PFP-NP		NHI-N		NHI-P		NHI-NP	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Sowing time												
Normal	24.26	25.02	36.39	37.53	14.56	15.01	66.4	66.0	58.5	57.8	65.0	64.6
Late	18.43	19.05	27.65	28.58	11.06	11.43	66.1	65.6	56.5	56.0	64.4	63.9
SEm±	0.37	0.35	0.55	0.53	0.22	0.21	0.3	0.1	0.4	0.0	0.2	0.1
CD (P=0.05)	1.16	1.11	1.73	1.66	0.69	0.66	NS	0.3	1.4	0.1	NS	0.3
Varieties												
RCr-41	19.65	20.28	29.48	30.43	11.79	12.17	65.6	65.2	57.0	56.3	64.1	63.7
RCr-435	21.94	22.60	32.90	33.90	13.16	13.56	66.3	65.8	57.3	56.8	64.8	64.2
RCr-480	22.45	23.22	33.68	34.83	13.47	13.93	66.7	66.5	58.2	57.7	65.3	64.9
SEm±	0.45	0.43	0.68	0.65	0.27	0.26	0.3	0.1	0.5	0.1	0.3	0.1
CD (P=0.05)	1.42	1.35	2.12	2.03	0.85	0.81	1.0	0.4	NS	0.3	0.9	0.3
Plant growth regulators												
Control	18.80	19.63	28.20	29.45	11.28	11.78	65.4	64.9	57.4	56.9	63.9	63.4
Tricontanol @ 1000 ppm	23.00	23.68	34.50	35.53	13.80	14.21	65.8	65.9	57.3	57.1	64.3	64.3
Brassinolide @ 1 ppm	22.75	23.30	34.13	34.95	13.65	13.98	66.8	66.3	57.7	56.9	65.2	64.7
Thiourea @ 1000 ppm	21.22	21.92	31.83	32.88	12.73	13.15	66.2	65.7	56.8	56.2	64.6	64.1
NAA @ 50 ppm	20.97	21.63	31.45	32.45	12.58	12.98	66.9	66.4	58.2	57.4	65.5	64.9
SEm±	0.40	0.41	0.61	0.62	0.24	0.25	0.2	0.1	0.3	0.3	0.2	0.1
CD (P=0.05)	1.15	1.17	1.72	1.76	0.69	0.70	0.5	0.3	0.9	0.8	0.5	0.3

total PFP (13.47 and 13.93) and NHI (65.3 and 64.9%) as well as individual nutrient PFP and NHI were recorded significantly higher with RCr-480 and remained at par with RCr-435 compared to RCr-41 in both the years. Nutrient uptake is a cumulative effect of content and biomass yield, so the varieties having higher content will not every time uptake the higher nutrients.

During both years essential oil content in RCr-480 variety seed (0.379 and 0.393%), oil yield (5.11 and 5.47 kg/ha) and protein yield (251 and 266 kg/ha) was recorded significantly higher as compared to RCr-41, respectively, being at par with RCr-435 (Table 4). The results of the present investigation indicate differential behavior of coriander varieties with respect to nutrient content, quality and its uptake is in close conformity with findings of other workers (AICRPS 2011 and Balai and Keshwa 2011).

Effects of plant growth regulators

Foliar spray of plant growth regulators (PGRs) significantly increased the yields, per-day-productivity and net returns of coriander as compared to water sprayed (control). Among the PGRs, foliar spray of 1 000 ppm triacontanol enhanced significantly seed (1 380 and 1 421 kg/ha and stover (2 061 and 2 152 kg/ha) yields, productivity (10.37 and 10.60 kg/day/ha) and net returns (₹ 218 and 228/day/ha) as compared to water sprayed, 50 ppm NAA and 1000 ppm thiourea being at par with 1.0 ppm brassinolide (Table 1 and 2). Under all the PGRs treatments the increase in seed and stover yields, per-day productivity and net returns was 10-22, 6-22, 10-22 and 20-46% over control, respectively. This might be due to the stimulatory effect of growth regulators which induced large number of reproductive sinks leading to greater activity of carboxylating enzymes (ribose 1,5-di phosphate carboxylase) resulting in higher photosynthetic rates with greater translocation and accumulation of metabolites in sink (Nehara *et al*. 2006) and ultimately higher seed yield. The cost of triacontanol was lower in comparison to added outputs. Thus, the increased seed yield led to higher net returns. The similar response with foliar spray of triacontanol was also reported by Nehara *et al*. (2006) in fenugreek and Sarada *et al*. (2008) in coriander.

Foliar application of plant growth regulators was also brought significant effect on nutrient content, uptake and quality of coriander (Table 1 and 2). Foliar spray of 1 000 ppm thiourea recorded significantly higher nitrogen content in both seed (3.11 and 3.19%) and stover (1.029 and 1.067%) as compared to control but found to be statistically at par with other PGRs treatment. Phosphorus content in seed and stover were significantly higher under foliar spray of 1.0 ppm brassinolide as compared to control and statistically at par with other PGRs treatment. However, foliar spray of 1 000 ppm tricontanol recorded significantly higher total N (62.0 and 65.7 kg/ha) and P (12.9 and 13.9 kg/ha) uptake (Fig 1 and 2) as well as individual nutrient uptake by seed and stover over control and 50 ppm NAA but

Table 4. Effect of sowing time, varieties and plant growth regulators on protein and essential oil content in seed and yields of coriander

Treatments	Protein content (%)		Protein yield (kg/ha)		Essential oil content (%)		Oil yield (kg/ha)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Sowing time								
Normal	17.8	18.3	260	275	0.383	0.397	5.58	5.96
Late	19.3	19.8	215	227	0.357	0.370	3.95	4.23
SEm±	0.27	0.23	6	6	0.005	0.004	0.05	0.06
CD (P=0.05)	0.84	0.73	20	20	0.015	0.014	0.17	0.19
Varieties								
RCr-41	18.1	18.6	214	227	0.361	0.373	4.26	4.54
RCr-435	18.9	19.3	248	261	0.371	0.385	4.88	5.22
RCr-480	18.6	19.1	251	266	0.379	0.393	5.11	5.47
SEm±	0.33	0.28	8	8	0.006	0.005	0.08	0.09
CD (P=0.05)	NS	NS	24	24	0.018	0.017	0.23	0.24
Plant growth regulators								
Control	16.6	17.0	187	200	0.331	0.344	3.73	4.05
Tricontanol @ 1000 ppm	18.6	19.1	255	271	0.383	0.397	5.29	5.64
Brassinolide @ 1 ppm	19.1	19.6	261	273	0.371	0.384	5.06	5.37
Thiourea @ 1000 ppm	19.4	19.9	247	262	0.391	0.406	4.98	5.34
NAA @ 50 ppm	18.9	19.4	238	251	0.376	0.388	4.73	5.04
SEm±	0.28	0.27	8	8	0.006	0.005	0.06	0.07
CD (P=0.05)	0.80	0.76	22	22	0.016	0.015	0.18	0.20

remained statistically at par with 1.0 ppm brassinolide and 1 000 ppm thiourea except in thiourea N uptake by stover during 2011-12, P uptake by seed in both the years and uptake by stover in 2011-12, respectively. The application of PGRs increased 22-36% and 14-28% in total N and P uptake over control. Total PFP (13.80 and 14.21) as well as individual nutrients PFP were recorded significantly higher with 1 000 ppm traicontanol, and remained at par with 1.0 ppm brassinolide and total NHI (65.5 and 64.9%) with 50 ppm NAA, and remained at par with 1 000 ppm thiourea and control in NHI-P as well as the individual nutrient as compared to other PGRs treatment and control.

However, the significantly higher protein (19.4 and 19.9%) and essential oil content (0.391 and 0.406%) in seed under 1 000 ppp thiourea over control and 50 ppm NAA. The significantly higher protein yield (261 and 273 kg/ha) were recorded under 1.0 ppm brassinolide over control and oil yield (5.29 and 5.64 kg/ha) was recorded with 1 000 ppm triacontanol than rest of the treatments of PGRs and control. The increase in nitrogen content in seed, stover, protein and essential oil content in seed with thiourea application might be due to improvement of metabolic processes and better growth and development, leading to greater absorption of nutrients from rhizosphere leads to increase yield and quality. Thiourea also creates better microbial population in soil which are responsible to mobilize essential nutrients. The quantum of nutrient uptake and oil yield by the crop is dependent on biomass production and nutrient content at cellular level. Since, nutrients content are improved by application of PGRs, the total biomass production is primarily responsive for the quantum of nutrient uptake. These results are in close conformity with the findings of Balai and Keshwa (2011) and Nehara *et al.* (2006).

Thus, on the basis of results of 2-years investigation, it could be concluded that sowing of coriander variety RCr-480 in first week of November with foliar application of 1 000 ppm triacontanol at 40 and 70 DAS gives higher yield, per-day-productivity and net returns, nutrient uptake and quality of coriander seed in semi-arid eastern plain zone of Rajasthan.

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Integrated nutrient management induced changes in nutrient uptake, fruit yield and quality of Kinnow mandarin

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ABSTRACT

The present study on the integrated nutrient management in Kinnow mandarin involved application of inorganic fertilizers, vermicompost and *Azotobacter* under different combinations. The pooled data analysis indicated that highest concentration of leaf and fruit N (2.57 and 0.06%), Ca (4.31 and 0.033%) and Mg (0.46 and 0.024%) with the combined application of *Azotobacter* + 25% nitrogen as vermicompost and 75% nitrogen as urea. Maximum leaf and fruit P (0.19 and 0.025%) were recorded with the application of vermicompost (to supply 50% N) and urea (to supply 50% N) augmented with *Azotobacter*. While highest leaf and fruit K (1.56 and 0.092%) were recorded with full doze of nitrogen applied as vermicompost along with *Azotobacter*. Maximum *Azotobacter* counts (31.6 × 10^6 cfu g soil), bacterial counts (28.9 × 10^6 cfu g soil) and fungal counts (35.5 × 10^5 cfu g soil) were recorded with the application of full doze of nitrogen through vermicompost alongwith *Azotobacter*. The results suggested that 25% nitrogen can be replaced through chemical fertilization along with vermicompost on N- equivalent basis plus *Azotobacter* inoculation.

Keywords: *Azotobacter*, Integrated nutrient management, Kinnow, Leaf nutrients, Quality, Yield

Kinnow mandarin is highly nutrient responsive and a balanced nutrition programme is mandatory to maintain a sustained productive life of orchard in addition to quality production (Ghosh 1990). There has been a surge of interest to adopt certain measures such as Integrated Nutrient Management (INM) for making its culture eco-friendly by reducing the tradition of inorganic fertilizers, pesticides and other synthetic formulations. Use of inorganic fertilizers along with organic manures and biofertilizers is a proven technology to build up the fertility status of the soil (Srivastava and Ngullie 2009a, Srivastava and Singh 2009b). Organic manure like vermicompost is rich in plant nutrients compared to other organic manures in respect of supply of N, P and K (Srivastava *et al*. 2001, Srivastava and Singh 2009c). Vermicompost application is one of the effective methods to rejuvenate the depleted soil fertility and enrich the available pool of nutrients, maintain soil quality and conserve more biological resources (Srivastava *et al*. 2001). On the other hand, biofertilizers are preparations containing living cells or latent cells of efficient strains of microorganisms that help crop plants uptake of nutrients by their interactions in the rhizosphere when applied through seed or to soil (Srivastava and Ngullie 2009a). *Azotobacter*, a free living microbe, acts as plant growth promoting rhizobacteria (PGPR) in the rhizosphere of almost all crops. (Gomare *et al*. 2013). *Azotobacter* produces many growth regulators such as IAA and GA which positively influence plant growth (Sharma and Kumar 2008). However, soil application of nutrients does not provide a clear picture of nutrient status of plant (Srivastava *et al.* 2001). In fruit crops like citrus, leaves have been found to be practically sensitive and convenient index of the nutrient status of the plant (Srivastava *et al.* 2008). Lot of research is being done on use of integrated supply of nutrients based on soil fertility status but information on leaf nutrient uptake and its correlation with yield and quality parameters is lacking (Marathe *et al*. 2012). Hence, the study was carried out to find the most suitable combination of inorganic fertilizers, organic manure and biofertilizer and its possible effects on nutrient status, yield, quality and soil microbial populations in Kinnow mandarin.

MATERIALS AND METHODS

This study was conducted on six year old Kinnow plants grafted on rough lemon rootstock having uniform shape, size and vigour. The experiment was laid out in the research orchard of Division of Fruit Science, Faculty of

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Agriculture, Udheywalla, SKUAST-Jammu during 2013 and 2014 in the sub-tropical zone at latitude of 32.43° North and longitude of 74.54° East. The experimental soil had pH 7.09, sand 65.5%, silt 18.5%, clay 17.0%, organic carbon 0.53%, electrical conductivity 0.14 ds/m, available nitrogen 222.5 kg/ha, available phosphorus 13.45 kg/ha, available potassium 140.5 kg/ha, available calcium 6.84 meq/100g, available magnesium 2.82 meq/100g. Recommended dose of NPK as per Package of practices for horticulture crops-SKUAST-J for Kinnow was maintained in the experiment, where only nitrogen was manipulated through different sources of fertilization. A total of 12 treatments replicated thrice were evaluated in a randomized block design: T_1: 100% N as urea, T_2: 25% N as vermicompost and 75% N as urea, T_3: 50 % N as vermicompost and 50% N as urea, T_4: 75% N as vermicompost and 25% N as urea, T_5: *Azotobacter* + 100% N as urea, T_6: *Azotobacter* + 25% N as vermicompost and 75% N as urea, T_7: *Azotobacter* + 50% N as vermicompost and 50% N as urea, T_8: *Azotobacter* + 75% N as vermicompost and 25% N as urea, T_9: *Azotobacter* + 100% N as vermicompost, T_{10}: 100% N as vermicompost, T_{11}: *Azotobacer* application and T_{12}: Absolute control.

The treatment wise application of vermicompost was applied to the trees around the trunk in the first week of January along with phosphatic fertilizers. Whole potash and first half dose of urea was applied 15 days before flowering and remaining half dose of urea was applied after fruit set. The biofertilizer *Azotobacter* was supplied with a uniform dose of 100 g / plant mixed with 10% jaggery solution prepared separately for each tree and was fed to the roots after one month of chemical fertilization.

Leaf samples were collected from seven months old spring cycle leaves on non fruiting terminals in the month of July (Chahill *et al*. 1988, Srivastava *et al*. 1994, Srivastava *et al*. 1999), thoroughly washed and ground to have a homogenous sample as per method described by Chapman (1964). Nitrogen was estimated by Micro-Kjeldahl's method as suggested by Jackson (1973). Phosphorus was determined by Vanado-molybdophosphoric acid yellow colour method (Jackson, 1973). Potassium was estimated using flame photometer and Ca, Mg was measured using atomic absorption spectrophotometer. Composite soil sample from the Kinnow rhizosphere of each treatment was used for estimation of soil microbial population following serial dilution method using specific media for each microbe (Black *et al*.1965). The pooled mean was generated during the course of study were subjected to statistical analysis and were tested on SPSS (Version 16) software using Duncan's multiple–ranged test to identify the homogeneous type of the data sets among different treatments.

RESULTS AND DISCUSSION

Leaf nutrient content

The effect of integrated sources of nitrogen on Kinnow showed significant differences among all the macro nutrients and are presented in Table 1 where, highest leaf nitrogen content (2.57%) was recorded in T_5 (*Azotobacter* + 100% N as urea) and T_6 (*Azotobacter* + 25% N as vermicompost and 75% N as urea). Leaf phosphorus reached to a highest level of 0.19% under T_7 (*Azotobacter* + 50% N as vermicompost and 50% N as urea) followed by T_8 (*Azotobacter* + 75% N as vermicompost and 25% N as urea) where leaf phosphorus 0.18% was obtained. T_9 (*Azotobacter* + 100% N as vermicompost) registered highest leaf potassium (1.56%) while, lowest leaf potassium content was obtained under control. Maximum leaf calcium (4.31%) was recorded in T_6 (25% nitrogen as vermicompost + 75% nitrogen as urea + *Azotobacter*) followed by plants receiving 50% nitrogen as vermicompost and 50% nitrogen as urea + *Azotobacter* (T_7). Treatment T_6 (25% nitrogen as vermicompost + 75% nitrogen as urea + *Azotobacter*) and T_7 (*Azotobacter* + 50% N as vermicompost and 50% N as urea) registered highest leaf magnesium content (0.46% each) followed by 0.45% under T_5 (100% nitrogen as urea in combination with *Azotobacter*). Minimum values for leaf macro nutrients were recorded under control. This may be due to the production of enzymatic complexes by nitrogen fixers which might have solubilized the unavailable form of nutrient elements and render them available. Increase in nitrogen content of the leaves with urea application has also been reported by Lal *et al.* (2000) in guava. The increase in phosphorus uptake might have been due to the better availability and translocation of phosphorus under *Azotobacter* application. Leaf nitrogen, phosphorus and potassium content of Kinnow mandarin were high when vermicompost was added as reported by Yadav *et al.* (2013) due to addition of organic manure in guava. Increase in foliar potassium content obtained in the present study is in conformity with the findings of Singh and Sharma (1993) in case of sweet orange cv. Mosambi.

Table 1 Leaf macronutrient composition of Kinnow mandarin as affected by different INM treatments (Pooled mean of two years)

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)
T_1	2.51^{g}	0.13^{c}	1.47^{c}	4.25^{f}	0.42^{d}
T_2	2.51^{g}	0.13^{c}	1.50^{e}	4.28^{fgh}	0.43^{de}
T_3	2.47^{f}	0.15^{d}	1.51^{f}	4.27^{f}	0.42^{d}
T_4	2.38^{d}	0.15^{de}	1.53^{g}	4.09^{c}	0.39^{c}
T_5	2.57^{i}	0.16^{f}	1.48^{d}	4.29^{ghi}	0.45^{ef}
T_6	2.57^{i}	0.17^{g}	1.52^{fg}	4.31^{i}	0.46^{f}
T_7	2.54^{h}	0.19^{h}	1.54^{h}	4.30^{hi}	0.46^{f}
T_8	2.42^{e}	0.18^{g}	1.55^{hi}	4.21^{e}	0.42^{d}
T_9	2.39^{d}	0.15^{e}	1.56^{i}	4.18^{e}	0.42^{d}
T_{10}	2.35^{c}	0.15^{d}	1.48^{d}	4.12^{d}	0.37^{c}
T_{11}	2.33^{b}	0.12^{b}	1.45^{b}	3.79^{b}	0.34^{b}
T_{12}	2.25^{a}	0.09^{a}	1.42^{a}	3.42^{a}	0.24^{a}

Fruit nutrient content

Data regarding effect of different INM treatments on fruit nutrient content is presented in Table 2. Highest fruit nitrogen content (0.06%) was achieved under T_5 (100% nitrogen as urea in combination with *Azotobacter*) and T_6 (25% nitrogen as vermicompost + 75% nitrogen as urea + *Azotobacter*) followed by T_1 (100% nitrogen as urea), T_2 (25% nitrogen as vermicompost + 75% nitrogen as urea) and T_7 (50% nitrogen as vermicompost and 50% nitrogen as urea + *Azotobacter*) where 0.05% fruit nitrogen was recorded. Fruit phosphorus reached to a highest level of 0.025% under T_7. Highest fruit potassium (0.092%) was recorded under T_9 (100% nitrogen as vermicompost + *Azotobacter*). Calcium content (0.033%) was highest under T_6 (25% nitrogen as vermicompost + 75% nitrogen as urea + *Azotobacter*) and T_7 (50% nitrogen as vermicompost and 50% nitrogen as urea + *Azotobacter*). Magnesium content in fruits did not show much significant difference among different treatments and ranged from 0.018 to 0.024%, lowest being observed in control (T_{12}). The above results are in line with the studies of Rana (2001) who found increase in nitrogen, potassium and calcium content of strawberry due to nitrogen and *Azotobacter* application and also reported no effect of various nitrogen fixers and urea on magnesium content of the berries. The findings on leaf and fruit nutrient content with the integrated application of inorganic fertilizers, organic manures and biofertilizers are in conformity with those reported in guava (Sharma *et al*. 2013, 2016) and Nagpur mandarin (Srivastava *et al*. 2008, 2015).

Correlation of macronutrients with yield and quality parameters

The correlation coefficient values (Table 3) indicated that fruit yield was significantly correlated with all the macronutrients in leaf. Highest significant positive correlation was observed with N (r = 0.925) followed by Mg (r = 0.759), Ca (r = 0.677) and P (r = 0.558). These findings are in conformity with the works of Marathe *et al.* (2012) in sweet orange. Trivedi *et al*. (2012) observed that incorporation of vermicompost and biofertilizers resulted in the maximum uptake of nitrogen and higher fruit yield in guava cv. Sardar. Highest degree of correlation was observed in case of juice content % with N (r = 0.966) followed by Mg (r = 0.852), Ca (r = 0.837) and P (r = 0.559). Srivastava *et al*. (2001) reported significant correlation of % juice with leaf N levels. Total soluble solids showed a strong positive correlation with P (r = 0.927) followed by Mg (r = 0.900), Ca (r = 0.893), K (r = 0.793) and N (r = 0.679). Total sugar content in fruits had a positive correlation (r = 0.946) with leaf P content followed by K (r = 0.860) and Mg (r = 0.855). Ascorbic acid content was correlated with leaf K (r = 0.778) followed by Ca (r = 0.740), P (r = 0.727) and Mg (r = 0.722). Such information would lead to find out the multiple nutrient deficiencies to manage them through site specific nutrient management (Srivastava and Singh 2015)

Table 2 Fruit nutrient composition of Kinnow mandarin as affected by different INM treatments (pooled mean of two years)

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)
T_1	0.05^{e}	0.021^{e}	0.072^{b}	0.029^{g}	0.022^{c}
T_2	0.05^{de}	0.022^{a}	0.074^{c}	0.030^{h}	0.022^{c}
T_3	0.04^{c}	0.023^{e}	0.078^{d}	0.032^{ef}	0.022^{c}
T_4	0.04^{c}	0.022^{c}	0.079^{d}	0.028^{fg}	0.022^{c}
T_5	0.06^{g}	0.023^{g}	0.083^{e}	0.032^{g}	0.024^{d}
T_6	0.06^{f}	0.023^{c}	0.086^{f}	0.033^{cd}	0.024^{d}
T_7	0.05^{e}	0.025^{d}	0.088^{f}	0.033^{h}	0.024^{d}
T_8	0.04^{d}	0.023^{d}	0.091^{g}	0.031^{de}	0.021^{b}
T_9	0.04^{c}	0.022^{f}	0.092^{g}	0.029^{fg}	0.024^{d}
T_{10}	0.03^{bc}	0.019^{g}	0.081^{e}	0.028^{bc}	0.022^{c}
T_{11}	0.03^{b}	0.018^{f}	0.070^{b}	0.027^{b}	0.022^{c}
T_{12}	0.02^{a}	0.016^{b}	0.060^{a}	0.024^{a}	0.018^{a}

Table 3 Correlation of leaf nutrient content with yield and quality of kinnow mandarin

Leaf nutrient	Coefficient of correlation (r) values				
	Yield	Quality parameter			
		Juice content	TSS	Total sugars	Ascorbic acid content
N	0.925**	0.966**	0.679**	0.605*	0.365
P	0.558*	0.559*	0.927**	0.946**	0.727**
K	0.268	0.342	0.793**	0.860**	0.778**
Ca	0.677**	0.837**	0.893**	0.848**	0.740**
Mg	0.759**	0.852**	0.900**	0.855**	0.722**

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

Soil microbial population

Soil microbial populations showed significant differences under different integrated nutrient management

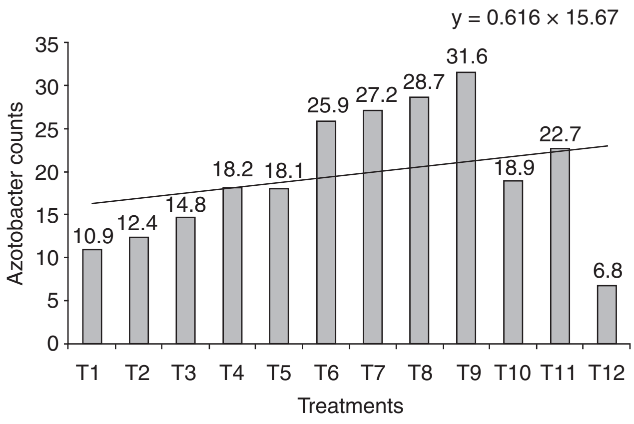

Fig 1 Effect of urea, vermicompost and *Azotobacter* treatments on *Azotobacter* population (× 10^6 cfu per gram soil) in rhizosphere of Kinnow mandarin (pooled mean of two years)

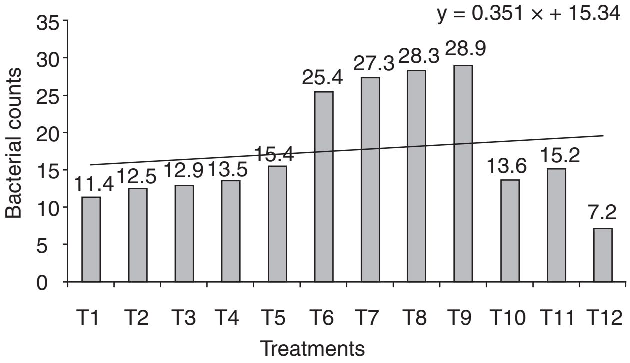

Fig 2 Effect of urea, vermicompost and Azotobacter treatments on bacterial population (×106 cfu per gram soil) in rhizosphere of Kinnow mandarin (pooled mean of two years)

treatments (Fig 1, 2 and 3). Maximum *Azotobacter* population (31.6×10^6 cfu per gram soil), bacterial population (28.9×10^6 cfu per gram soil) and fungal population (35.5×10^5 cfu/g soil) was observed in T_9 (100% nitrogen through vermicompost + *Azotobacter*). Panigrahi and Behera (1993) also observed higher *Azotobacter* population at lower level of nitrogen which is in conformity with the present finding. It has been observed that organic matter serves as energy source for growth and multiplication of *Azotobacter*. It was observed that increased nitrogen application reduced microbial population. Results are in agreement with the findings of Sharma *et al.* (2010, 2013) on apricot and Huchche *et al*. (1998).

From the present studies, it is evident that integrated nutrient management system standardized the schedule of manure and fertilizer application in Kinnow mandarin for sustaining the soil fertility to enhance the production potential and reduce the requirement of chemical fertilizers. The findings have clearly indicated that there was a positive effect of fertilizers when N was manipulated through different sources, viz. vermicompost, biofertilizers and inorganic fertilizers. The results also indicated that there was substantial improvement in leaf and fruit nutrient status of Kinnow mandarin through use of integrated nutrient management system comprising inorganic fertilizers, vermicompost and *Azotobacter*. The nutrient content in leaf further supplemented via significant correlation with fruit yield and quality parameters. Also integration of organic manure along with *Azotobacter* increased soil health in terms of microbial populations. Based on the experimental results obtained, it may finally be concluded that application of 25 % N applied through urea could be replaced with vermicompost application of nutrient equivalent basis along with inoculation of *Azotobacter* @100 g/tree for increasing the nutrient status of Kinnow mandarin. At the same time, integrated nutrient management could effectively address the environmental and sustainability concerns without losing out on productivity.

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Effect of plant density and foliar nutrient application on seed yield and quality in Asiatic carrot (*Daucus carota*)

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ABSTRACT

A field experiment was conducted to study effect of plant density and foliar spray of nutrients on carrot (*Daucus carota* L.) seed yield and quality during winter season of 2012-13 and 2013-14. Plant height, days to 50% flowering, number of umbels/plant, number of seeds/umbel, seed yield/umbel, percentage contribution of different order umbel to total seed yield, seed yield/plant, seed yield/ha, 1 000 seed (mericarp) weight, germination (%) and vigour index were recorded. Significant highest average plant height, earliness in days to 50% flowering and seed yield/ha (12.9 q) were observed in high plant density (13 plants/m^2). More number of secondary (11.6) and tertiary umbels (30.1) and higher seed yield/plant (25.2g) were recorded in low plant density (4 plants/m^2). Per cent contribution of primary umbel to total seed yield was maximum (41.76%) in 13 plants/m^2 and minimum (16.89%) in 4 plants/m^2. But an increasing trend in contribution percentage to total seed yield by secondary and tertiary umbels was recorded from 13plants/$m^2$to 4plants/m^2.Seeds from primary and secondary umbels recorded high quality in plant density of 5 plants/m^2 and 4 plants/m^2 respectively.Comparative reduction in pooled seed vigour was observed in 7 plants/m^2 and 13 plants/m^2. Foliar spray of 0.1% $MgSO_4$at 30 and 60 days after transplanting (DAT) increase the seed quality. Both seed yield and qualityincrease was observed in 0.1% borax spray at 30 and 60 DAT.

Key words: Borax, Carrot, Foliar nutrient spray, $MgSO_4$, Plant density, Seed quality, Seed yield

Carrot (*Daucus carota* L.) is one of the important root vegetable in umbelliferae family. It covers an area of 62.4 thousand ha in India with the production of 10.7 lakh tonnes (Saxena and Gandhi 2015). Both Asiatic and temperate type carrots are cultivated in India but they require different climatic condition for their seed production. Seeds of Asiatic type can be produced in plains but that of temperate types in hilly region only. Carrot inflorescence consistsof many branches and is divided into different order umbels (primary, secondary and tertiary etc.) based on their position and developmental stages. This also leads to production of seeds in different maturity levels. When the primary umbel reaches maturity the secondary or tertiary umbels may be in immature or flowering stage, respectively. This is one of major problem in seed production of carrot crop. Highest contribution by primary umbel to total seed yield in high density planting in temperate carrot was demonstrated (10 to 80 plants/m^2, 2-84 plants/$m^2$and 2-100 plants/m^2) by many authors (Gray *et al*. 1983, Gray and Steckel 1983 and Merfield *et al*. 2010). High quality seeds are generally produced from primary and secondary umbels in carrot (Pandita *et al.* 2005). This indicates promotion of primary and secondary umbel by increasing plant density may promote uniform maturity and quality of seeds. But there is a need of fine balance between increase in plant density, increase in seed yield and maintenance of seed quality. One should not compromise seed quality for higher seed yield by increasing plant density. The optimum plant density also depends upon environment and cultivars. Apart from plant density, balanced nutrition of macro and micronutrients also play a vital role in increase and enhancement of seed yield and quality. In this study an attempt was made to suppress the side branches of inflorescence by increasing the plant density in carrot and to know the supportive effect off oliar nutrient for obtaining higher seed yield and quality in carrot.

MATERIALS AND METHODS

The experiment was conducted at Seed Production Unit of Indian Agricultural Research Institute, New Delhi during the period of September to May, 2012-13 and 2013-14. The experimental site was situated at 28°35’N latitude & 77°12’E longitude and at an altitude of 228.6 m above mean sea level. Seeds of carrot cv. Pusa Rudhira were sown in the last week of September and transplanting of uniform size steckling was done in third

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week of January. Split plot design was adopted to conduct experiments with plant density as main plot treatment and foliar spray of nutrients as sub-plot treatments. Stecklings were transplanted with spacing of 15×50cm, 30×50cm, 40×50cm and 50×50cm which gave plant density of D_1-13 plants/m^2, D_2-7 plants/m^2, D_3-5 plants/m^{2}and D_4-4 plants/m^2 respectively. Sub-plot size was 3m×3m and main plot consists of seven sub-plots for six foliar spray treatments and one control. Main plots were replicated three times with all sub-plot treatments. Foliar spray treatments consist of T_1-0.1% borax at 30 DAT, T_2- 0.1% borax at 60 DAT, T_3- 0.1% borax at 30+60 DAT, T_4- 0.1% Magnesium sulphate ($MgSO_4$) at 30 DAT, T_5- 0.1% $MgSO_4$ at 60 DAT, T_6- 0.1% $MgSo_4$ at 30+60 DAT and T_7- control (sprayed with water). Borax used as boron source. All the package of practices and plant protection measures were carried out as per recommendation. Days to 50% of flowering was counted from initiation of primary umbel to 50% flowering of primary, secondary and tertiary umbels in individual treatment. Plant height of 10 randomly selected plants was measured at the time of 50% of flowering. Number of umbels/plant, percentage contribution of all different order umbel(s) to total seed yield and seed yield/plant was estimated from average of observations taken from ten randomly selected plants at the time of harvest. Number of seeds/umbel and seed yield/umbel was estimated from 10 randomly selected umbels of different order. Seed yield/ha was estimated based on average of main plot and subplot seed yield. Seed quality parameters like 1 000 seed weight, germination percentage (ISTA 2012) and vigour index (Abdul-Baki and Anderson, 1973) were calculated. Since seeds of primary and secondary umbels were combined together in general seed lot, a pooled vigour index was also calculated by taking average of seed vigour index one of primary and secondary umbels. Statistical analysis was carried out by a software AgRes version 3.01.

RESULTS AND DISCUSSION

Growth attributes

In the present study higher average plant height with respect to primary (118.7cm), secondary (133.6cm) and tertiary (139.4cm) umbels were observed in highest plant density (D_1). This may be due to more apical growth and suppression of side branches. Similar results have also been reported by Ahmad and Tanki (1997) and Kumar (2005) in carrot. In case of other crops, increasing plant density generally reduces the plant height or length due to competition among plants for space, nutrient and sunlight. Bahlgerdi *et al*. (2014) observed highest plant length in medicinal pumpkin in lowest plant density. Highest plant density (D_1) recorded earliness for days to 50% flowering as compared to other plant densities. Decreasing plant density showed delay in days to 50% flowering. Earliness in flowering may be due to competition between plants in D_1. Andriolo (1999) reported that an optimized leaf area index (LAI) can be obtained by ideal population density for better interception of maximum useful radiation for photosynthesis. Before plants start the reproductive phase, an optimized LAI can be reached very early on high density

Table 1 Effect of plant density and foliar spray on growth and flowering in carrot cv. Pusa Rudhira (Pooled data of two season 2012-13 and 2013-14)

Treatment	Plant height (cm)			Days to 50 % flowering			Number of umbels/plant	
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	Secondary	Tertiary
plant density								
D_1	118.7^a	133.6^a	139.4^a	26.5^c	33.3^d	40.2^c	6.2^d	17.5^d
D_2	112.7^b	127.7^b	131.5^b	27.3^b	34.1^c	41.5^b	9.3^c	23.8^c
D_3	108.9^b	123.6^c	126.6^c	27.8^{ab}	34.5^b	43.0^a	11.3^b	27.5^b
D_4	104.1^c	121.5^c	124.5^c	28.3^a	35.0^a	43.4^a	11.6^a	30.1^a
CD (P=0.05)	3.96	2.97	3.96	0.60	0.34	1.02	0.12	1.10
Foliar nutrient spray								
T_1	110.0	126.1	129.4	27.1	33.8	41.5	9.6	24.6
T_2	112.0	127.5	130.6	27.5	34.1	42.0	9.7	25.1
T_3	113.3	128.6	131.5	27.8	34.6	42.4	9.7	25.7
T_4	110.4	125.1	130.2	27.1	34.0	41.5	9.5	24.0
T_5	110.9	126.8	130.9	27.6	34.1	42.0	9.6	24.6
T_6	111.8	128.1	131.8	28.1	34.8	42.9	9.6	25.3
T_7	109.2	123.9	129.1	27.1	33.8	41.8	9.5	23.8
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
D×T	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters are statistically different. Separation done by Duncan's Multiple Range Test.

plantings. Thus, planting density in any crop influences plant growth, changing the flower initiation and fruit development and interfering on the biomass distribution between source and sink.Number of umbels/plant increased with decrease in plant density and was highest in D_4 for both secondary (11.6) and tertiary umbels (30.1). This may be due to availability of more nutrient and sunlight to individual plants in low plant density. These results are in accordance with Kumar (2005) in carrot. None of the growth parameters were recorded significant difference with respect of foliar nutrient sprays. No significant interaction effect was observed between density and foliar nutrient spray for all growth attributes (Table 1).

Seed yield attributes

Highest number of seeds/primary umbel was observed in D_2 (1742) and D_3(1725) followed by D_1(1700) and D_4(1702). This indicates both reduction and increase in plant density affect the seed number in primary umbel. Lowest plant density (D_4) recorded highest number of seeds in secondary and tertiary umbel. Similar results were observed in onion by Asaduzzaman *et al.,* (2012). Seed yield/primary umbel was recorded higher and on par in D_2 (4.24g), D_3 (4.30g) and D_4 (4.22g) than D_1(4.03). Seed yield/secondary and tertiary umbels were highest in lowest plant density (D_4).

Percentage contribution by primary umbel (41.73%) to total seed yield was observed highest in high plant density (D_1). But D_3 and D_4 received significantly highest contribution from secondary umbels because increased number of secondary umbel in low plant density. Contribution of tertiary umbels to total seed yield (10.70%) was highest in lowest plant density (D_4). None of the foliar spray recorded significant differences with respect to percentage contribution in primary and secondary umbels. Seed yield/plant was highest (25.2g) in lowest plant density (D_4). But seed yield/ha was significantly higher (12.9q) in highest plant density (D_1). It may be due to increased plant population in high plant density (D_1).These results are similar with results obtained by Guerrero *et al*. (1986), Amjad and Anjum (2001), Lima *et al*. (2003)and Pandita *et al*. (2005) in temperate and tropical carrot cultivars.

Recent studies in watermelon (Edelstein and Nerson 2002), muskmelon (Nerson 2002), onion (Kanwar *et al*. 2000) and medicinal pumpkin (Bahlgerdi *et al*. 2014) showed that relatively high plant densities were required to obtain the highest seed yield. In contrary, there are few reports in seed production of winter squash and squash suggested low plant densities for higher seed yield (Dematte *et al*. 1978, Edelstein *et al*. 1985, Lima *et al*. 2003). Al Mamun *et al*., (2016) also reported that early planting of potato top shoot cutting with closer spacing (50×10 cm and 50×15cm) was most suitable for breeder seed multiplication. So optimization of plant density for seed production of any crop and their different cultivars are very important to obtain higher seed yield and seed quality.

Among the foliar sprays, T_3 recorded higher number of seeds, seed yield/umbel, seed yield/plant (20g) and seed yield/ha (12.3q). However, $T_6$was on par for number of seeds and seed yield/primary umbel with T_3. These results are in accordance with results obtained by Sharma *et al.* (1999), Vrataric *et al*. (2006) and Kumar *et al.,* (2012). For all seed yield attribute, significant interaction between density and foliar spray was not observed (Table 2).

Seed quality attributes

Highest 1 000 seed (mericarp) weight with respect to primary umbel was recorded in D_3 (2.489g) followed by D_2 (2.446g) and D_4 (2.476g). Many authors reported highest 1 000 seed weight of carrot in less plant density (Kumar 2005). In our study maximum seed weight was observed in D_3 instead of D_4. Higher number secondary and tertiary umbel in D_4 leads to slight quality reduction in seeds form primary umbel. Though, only primary umbels promoted in D_1, the reduced seed weight indicate the competition among the plants for various resources.

Similar kind of results was observed in *Cucurbita pepo*. L (Loy 1988) and medicinal pumpkin (Bahlgerdi *et al.* 2014). These results indicated requirement of optimum level of plant density for quality seed production instead of high or less plant density. Plant density had no significant effect on germination per cent of seeds from primary umbels. Seeds of secondary and tertiary umbels recorded highest germination at lowest plant density (D_4). Highest significant vigour index with respect to primary umbel was recorded in D_3 (1134) followed by D_2 (1077) and D_4 (1087). An increasing trend of vigour index was observed for seeds of secondary and tertiary umbel from highest (D_1) to lowest plant density (D_4). Foliar spray treatment T_3(2.472g) had maximum test weightfrom primary umbels and was on par with T_2 (2.457g) and T_6 (2.458g), 1 000 seed weight was observed highest with T_3 in secondary and tertiary umbel. Similar results were also observed in chilli (Dongre *et al.* 2000) and Niger (Paikray, *et al.,* 2001).

Among the foliar treatments, both T_3 and T_6 recorded significantly highest germination percentagein seeds from primary, secondary and tertiary umbel. T_3 followed by T_6 recorded highest vigour index for seeds of all order umbels. The following may be the reason for seed quality enhancement by T_6. Magnesium is central element in chlorophyll. It participates in activity of many enzymes and involved in phosphorous translocation (Curley 1994). Foliar 'boosting' of Mg through leaves may deliver the Carbon and Nitrogen containing compounds to the seeds which effectively increases the seed quality (Gerendas and Fuhrs 2013). Quality of seeds form primary umbel was always higher than the other order umbel in all the density and foliar treatments. Highest pooled vigour index was observed in D_3 (1082), D_4 (1071), T_3 (1102) and T_6 (1089). This indicates, less plant density and spraying of foliar nutrient was promoting the seed quality in carrot. Interaction effect of density and foliar nutrient spray was not significant for all the seed quality parameters. Germination per cent of seeds from tertiary umbel was always less than seed certification

Table 2 Effect of plant density and foliar spray on seed yield parameters in carrot cv. Pusa Rudhir (Pooled data of two season 2012-13 and 2013-14)

Treatments	Number of seeds/umbel			Seed yield/umbel (g)			Percentage contribution to total seed yield			Seed yield/ plant (g)	Seed yield/ ha (q)
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary		
Plant density											
D_1	1700^{b}	389^{c}	23^{d}	4.03^{b}	0.80^{d}	0.039^{d}	41.73^{a}	51.17^{c}	7.11^{c}	9.7^{d}	12.9^{a}
D_2	1742^{a}	609^{b}	27^{c}	4.24^{a}	1.33^{c}	0.045^{c}	24.05^{b}	69.94^{b}	6.01^{d}	17.7^{c}	11.8^{b}
D_3	1725^{a}	632^{b}	37^{b}	4.30^{a}	1.39^{b}	0.064^{b}	19.83^{c}	72.10^{a}	8.07^{b}	21.7^{b}	10.9^{c}
D_4	1702^{b}	692^{a}	48^{a}	4.22^{a}	1.57^{a}	0.089^{a}	16.89^{d}	72.41^{a}	10.70^{a}	25.2^{a}	10.3^{d}
CD (P=0.05)	21.71	26.11	2.74	0.09	0.03	0.002	0.58	0.74	0.34	0.29	0.23
Foliar nutrient spray											
T_1	1688^{c}	577^{bc}	32^{c}	4.14^{cd}	1.25^{bc}	0.059^{bc}	25.78	66.27	7.95^{abc}	18.3^{cd}	11.3^{bce}
T_2	1730^{b}	592^{b}	36^{b}	4.25^{b}	1.29^{b}	0.062^{ab}	25.52	66.18	8.30^{ab}	18.9^{b}	11.5^{b}
T_3	1793^{a}	621^{a}	40^{a}	4.40^{a}	1.36^{a}	0.066^{a}	24.74	66.74	8.52^{a}	20.0^{a}	12.3^{a}
T_4	1670^{c}	556^{c}	30^{cd}	4.07^{d}	1.23^{cd}	0.055^{c}	25.98	66.53	7.49^{c}	17.9^{de}	11.2^{ce}
T_5	1723^{b}	572^{bc}	32^{c}	4.21^{bc}	1.27^{bc}	0.058^{bcd}	25.84	66.36	7.80^{bc}	18.5^{bc}	11.4^{bce}
T_6	1772^{a}	588^{b}	35^{b}	4.35^{a}	1.30^{b}	0.062^{ab}	25.72	65.96	8.32^{ab}	19.1^{b}	11.5^{bc}
T_7	1644^{d}	557^{c}	28^{d}	3.95^{e}	1.20^{d}	0.053^{d}	25.78	66.79	7.44^{c}	17.3^{e}	11.1^{e}
CD (P=0.05)	26.53	24.29	2.40	0.09	0.05	0.004	NS	NS	0.71	0.60	0.30
D×T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters are statistically different. Separation done by Duncan's Multiple Range Test.

Table 3 Effect of plant density and foliar spray on seed quality of different order umbelsin carrot cv. Pusa Rudhira (Pooled data of two season 2012-13 and 2013-14)

Treatment	1000 mericarp weight (g)			Germination (%)			Vigour index			Pooled Vigour index
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	
Plant density										
D_1	2.357^{c}	2.089^{d}	1.778^{c}	71 (57.48)	67 (55.20)^{c}	40(39.08)^{c}	1024^{c}	933^{d}	507^{d}	978^{c}
D_2	2.446^{b}	2.162^{c}	1.808^{b}	73 (58.81)	71 (57.12)^{b}	42(40.15)^{bc}	1087^{b}	990^{c}	555^{c}	1039^{b}
D_3	2.489^{a}	2.240^{b}	1.844^{a}	75 (59.88)	72 (57.99)^{ab}	43(41.23)^{b}	1135^{a}	1030^{b}	593^{b}	1083^{a}
D_4	2.476^{ab}	2.286^{a}	1.858^{a}	74 (59.12)	74 (59.00)^{a}	50(44.94)^{a}	1077^{b}	1064^{a}	692^{a}	1071^{a}
CD (P=0.05)	0.04	0.04	0.02	NS	1.23	1.25	45.26	22.37	34.38	18.62
Foliar nutrient spray										
T_1	2.442^{ab}	2.188^{b}	1.816^{bc}	72 (57.90)^{c}	70 (56.55)^{bc}	42(40.31)^{bc}	1055^{cde}	980^{ce}	559^{cd}	1018^{cd}
T_2	2.457^{a}	2.211^{ab}	1.842^{ab}	73 (58.82)^{bc}	70 (57.05)^{bc}	44(41.61)^{ab}	1093^{bc}	1014b^{c}	601^{ab}	1054^{b}
T_3	2.472^{a}	2.231^{a}	1.857^{a}	75 (60.15)^{ab}	73 (58.86)^{a}	46(42.86)^{a}	1140^{a}	1064^{a}	642^{a}	1102^{a}
T_4	2.425^{bc}	2.180^{bc}	1.800^{cd}	72 (58.27)^{bc}	70 (56.47)^{bc}	42(40.40)^{bc}	1049d^{e}	976^{ce}	546^{d}	1013^{d}
T_5	2.445^{ab}	2.193^{b}	1.826^{b}	73 (58.84)^{bc}	72 (57.78)^{ab}	45(41.87)^{ab}	1077^{cd}	1012^{bc}	591^{bc}	1045^{bc}
T_6	2.458^{a}	2.210^{ab}	1.835^{ab}	76 (60.85)^{a}	73 (58.62)^{a}	46(42.76)^{a}	1137^{ab}	1041^{ab}	630^{ab}	1089^{a}
T_7	2.397^{c}	2.146^{c}	1.779d	70 (56.99)^{c}	69 (55.92)^{c}	41(39.68)^{c}	1015^{e}	944^{e}	538^{d}	980^{e}
CD (P=0.05)	0.03	0.04	0.03	1.93	1.52	1.63	43.63	45.09	41.45	30.62
D×T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by different letters are statistically different. Separation done by Duncan's Multiple Range Test. Values in parenthesis are arcsine transformed value.

standard of 60% in all the treatments (Table 3).

Though highest seed yield/ha was observed in 13 plants/m^2, we recommend 5 plants/m^2 is ideal for breeder and foundation seed production without quality reduction. Since seeds form primary and secondary umbels of all the plant density recorded germination per cent higher than ISTA seed standard (60%) for carrot, even we can adopt 13 plants/m^2 for certified seed production of carrot cv. Pusa Rudhira. Harvesting seeds from tertiary umbel must be avoided to maintain higher seed quality.

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