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ORIGINAL ARTICLE

Photoselective coverings influence plant growth, root development, and buddability of citrus plants in protected nursery

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Abstract
Use of protective coverings can be an economically viable option in fruit nurseries than in fully mature commercial orchards. In protected nurseries, photoselective coverings can influence the growth of rootstocks, budding success, and budding growth of the budded scion cultivar. The effect of photoselective coverings (white, silver, green, red and stainless steel net house) along with open conditions (control) was studied on plant growth, nutrient uptake and root growth of rough lemon and Carrizo citrange rootstock seedlings which were subsequently budded with Kinnow and Daisy mandarin cultivar buds, respectively. The rough lemon plants under red net had better height, internodal length and budding success, while in open conditions, higher seedling diameter, root diameter, shoot and root dry weight, leaf number and secondary root number were recorded in rough lemon seedlings. The Carrizo seedlings in red net had better seedling diameter, internodal length, leaf area and number, shoot dry weight and budding success. The higher nitrogen, phosphorus, potassium and zinc levels were recorded in the leaves of rough lemon and Carrizo citrange under red shade net. The plant height of rough lemon seedlings was positively correlated to internodal length, budding success and leaf areaas well as leaf phosphorus and iron levels. The highest buddable seedlings were recorded in open conditions but, budding success in red shade net house. The highest sprout lengths of Kinnow and Daisy mandarin saplings were recorded in red net followed by green net and white net. Higher photosynthesis and stomatal conductance were recorded under red shade net, whereas lowest PAR interception was recorded in open conditions.

Keywords Shade nets · Nutrient uptake · Photosynthesis · Stomatal conductance · Humidity · PAR

Introduction

In the entire world, citrus fruits cover 9.09 million ha with an annual production of 137.4 million tons. China (33.73 m tons), Brazil (19.51 m tons), India (11.65 m tons), Mexico (7.67 m tons), USA (6.78 m tons), Spain (6.95 m tons) and Egypt (4.80 m tons) are the major producers of citrus in the world (FAOSTAT 2016). Kinnow mandarin (*Citrus nobilis* Lour × *C. deliciosa* Tenora) was developed at University of California, Riverside, USA by H. B. Frost. It was introduced in India at Punjab Agricultural University (PAU), Research Station, Abohar, Punjab in 1954. Kinnow is now a leading variety of mandarin in North India, while Daisy mandarin (*Citrus reticulata* Blanco), a cross between Fortune and Fremont mandarins also developed in USA and introduced at PAU Fruit Research Station, Jallowal, Jalandhar, India in 2003 is also in high demand due to its early maturity, better colour, taste and juice content.

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Citrus grows well in subtropical and tropical climates, but high temperatures, especially during summers, hamper its growth. The nursery production of citrus plants takes around 2 years which involves growing of rootstock, budding and finally the growth of budded plants. The nursery production of citrus plants is usually done under protected conditions to enhance growth of the rootstock and budded plants, extend the period of budding operation and protect against pests.

Netting is a technology used for manipulation of light spectrum and protection of agricultural crops from high temperature and high evaporation rates due to overabundant solar radiation, pests or environmental hazards (Mahmood et al. 2018). The spectrally modified light improves the physiological responses of the under grown plants (Shahak et al. 2008). The solar radiation from the screens and shade nets used in protected horticulture is related to photosynthetically active radiation (PAR). The quality of light transmitted by these screens and shade nets depends upon their material properties (Kotilainen et al. 2018). Black nets do not alter spectral quality of light: pearl nets were most effective in reducing the transmittance of UV-radiation, while blue and red nets mostly alter the spectral quality in PAR or visible range. The red nets were least effective in reducing the transmittance of U V radiation (Arthurs et al. 2013). In leafy plants, the morphological characteristics like plant height, level of branching, leaf area and colour can be modified by use of photoselective shade nets. The red and yellow nets improved plant growth, blue nets imparted dwarfing and pearl nets improved fruit size, yield and postharvest quality in fruit crops (Alkalai-Tuvia et al. 2014; Ilic and Fallik 2017). In arid environment, blue photoselective netting improved photosynthetic light use efficiency in leaves and reduced transmittance of solar radiation and symptoms of photoinhibition under high light in apple (Mupambi et al. 2018). During the hot summer months, coloured nets reduced the light intensities similar to the ones during fall and spring season. The growth responses of different crops may vary under the same shade net (Ilic et al. 2015). Mostly the studies on the use of shade nets have been undertaken on vegetable crops (tomato, coriander, lettuce, and pepper) rice and blueberry (Ilic and Fallik 2017; and Mahmood et al. 2018). The studies undertaken on fruit crops viz. mango (Jutamanee and Onnom 2016), apple (Bastías et al. 2011), banana (Haijun et al 2015) and citrus (Germanà et al. 2001; Medina et al. 2002; Wachsmann et al. 2014; Incesu et al. 2016; Zhou et al. 2018) have been done to ascertain the influence of shade nets on fruit plants grown in orchards. However, it may not be always economically viable to use shade nets on fully mature commercial orchards on a sizeable area. The benefits of shade nets can be exploited in the protected nurseries where it can influence the growth of rootstocks, budding success and buddling growth depending upon cultivar.

In a tree fruit nursery, obtaining a desirable rootstock girth (7–8 mm) at an early stage for budding operation is more important than the rootstock height. After the budding operation of the rootstock with scion variety, rapid growth of buddlings is needed to achieve a desirable plant height at the earliest. This is desirable for achieving the maximum production efficiency of the costly protected structures used in a protected tree fruit nursery. Higher yield and fruit quality were reported in mandarin trees grown under different photoselective nets (Wachsmann et al. 2014). Besides, higher photosynthetic performances were reported in lime and oranges when grown under reflective nets (Medina et al. 2002). The use of photoselective nets had a significant influence on root distribution, shoot–root interaction and establishment of 4-year-old citrus trees in orchards (Zhou et al. 2018). It was hypothesized that the photoselective coverings can influence the growth, buddability and buddling growth of citrus nursery under protected conditions. Hence, the present studies were conducted to study the influence of photoselective coverings on growth, budding success and nutrient uptake in citrus rootstocks and budded saplings.

Methods

The experiments were conducted in Citrus Nursery, Department of Fruit Science, Punjab Agricultural University, Ludhiana, India, 29.3° N latitude and 76.5° E longitude, 270 m amsl during May, 2015 to August, 2017. The growing media, Soil + Farmyard manure + Cocopeat (2:1:1 v/v)] prepared in May, 2015 was spread in 30 cm-thick layers on a concrete floor. The soil used for growing media was Typic Ustochrept, sandy loam (131 g clay, 148 g silt and 721 g sand kg^{-1}) with 8.1 pH, 0.36 d Sm^{-1} salinity, 0.42% organic carbon, 25.5 kg ha^{-1} available phosphorus and 311.2 kg ha^{-1} potash. To eliminate soil-borne pathogens, the growing media was fumigated with Basamid® Granular (Dazomet 98%) @ 50 g m^{-2}. After the treatment, the layers of growing media were covered with transparent plastic sheet for 3 weeks for fumigation and solarization. The plastic sheet was removed after 3 weeks and two turnings were given to the media at weekly intervals. The potting media was filled in black polythene bags (30 × 15 cm size, 62.5 μ thickness). Rough lemon and Carrizo citrange seeds from citrus rootstock block which was developed by budding from single elite rootstock trees were sown in the polythene bags in August, 2015. These polythene bags were then shifted under different protective coverings as mentioned above under treatments. The seeds germinated in about 3 weeks, but more than one seedling germinated from a seed due to nucellar embryony. The extra seedlings were rouged-out to retain only one uniform sized seedling in a polybag. The rough lemon and Carrizo citrange rootstock seedlings were 'T–budded' at 23 cm above soil level with buds from Kinnow and Daisy mandarin, respectively. The buds were taken from 6-year-old Kinnow and 3-year-old Daisy mandarin mother plants grown in stainless steel screen houses (40 mesh). The budding operation in rough lemon and Carrizo citrange rootstocks was done during September, 2016 and March, 2017, respectively. The Kinnow and Daisy mandarin buddlings sprouted from the buds were maintained under the different protective conditions. All the cultural operations viz. irrigation, weeding and plant protection measures were uniform for all the experimental plants.

Treatments

The rough lemon and Carrizo citrange rootstock seedlings were maintained under five different protective structures (96′×32′×10′) with covering viz. (1) High-density polyethylene (HDPE) green shade net (50%), (2) HDPE red shade net (50%), (3) HDPE white shade net (50%), (4) HDPE silver shade net (50%), (5) stainless steel screen houses (40 mesh) and (6) open conditions (control). The netting material comprised interwoven threads made of HDPE. The colour of netting material (Table 1) was recorded with Hunter Lab colour meter (ColorFlex®, EZ, USA). The chromacity '*L*', '*a*' and '*b*' values were obtained from the Hunter Lab Colour meter. The chroma was calculated as $C=(a^2+b^2)^{½}$ which shows the intensity of colour saturation from dull to vivid colour depicted by low to high values, respectively. The hue angle ($h°$) was calculated by equation $\tan^{-1} b/a,$ which represents red at 0° or 360°, yellow at 90°, green at 180° and blue at 270°.

Observations recorded

The different growth parameters such as seedling height, stem diameter, internodal length, number of leaves, leaf area, root pattern, length of tap root, diameter of the tap root, number of secondary roots and biomass were recorded for the rough lemon and Carrizo citrange rootstock seedlings before the budding operation. The leaf area was measured with Leaf area meter 211 (Systronics, India). The photosynthetic parameters viz. photosynthetic rate, photosynthetically active radiation, stomatal conductance and intercellular carbon dioxide were measured by the LI-6400Xt portable photosynthesis system (Li-Cor BioSciences, Inc. USA). The meteorological parameters viz. canopy temperature (°C) and relative humidity (%) were measured using hand-held humidity and Temperature Meter–CEM DT-615 (Shenzen Everest Machinery Industry CO., Ltd, China). The chlorophyll content was measured by Chlorophyll Meter SPAD-502 plus at the continuous interval of 15 days. The maximum and minimum temperatures were recorded with India Meteorological Department (IMD) maximum and minimum thermometers fixed in each net house. The chlorophyll content and photosynthetic parameters were measured for the Rough lemon and Carrizo citrange rootstock seedlings from July, 2016 onwards when the seedlings achieved sufficient height (30 cm) and leaf size required for the analysis.

The growth characteristics of Kinnow and Daisy mandarin buddings viz. sprout length, sprout diameter and number of leaves per plant were recorded after 7, 9 and 11 months after budding for Kinnow mandarin; 3, 4 and 5 months after budding for Daisy mandarin and the final data recorded in August, 2017. The sampling for analysis of plant nutrients was done as per Bhagat et al. (2013). The total nitrogen was estimated by following the Kjeldahl's method: total phosphorus, potassium, zinc and iron levels were estimated in triple-acid (nitric acid: sulphuric acid: perchloric acid, 10:3:1) digests. The ammonium molybdate method was used for phosphorus, flame photometer method for potassium and atomic absorption spectrometry for zinc and iron as described in Singh et al. (2018). The experiment was laid as Completely Randomized Design having three replications with $n=150$. In the experiment, 1800 rootstock seedlings were under study with 900 seedlings of rough lemon and Carrizo seedlings each. The data were analysed using statistical software SAS 9.3. The mean separation was done using (LSD) least significant difference at $p \leq 0.05$ following significant ANOVA. The Principal component analysis was done using statistical software XLSTAT Trial (v 2018 Trial, Addinsoft, USA).

Table 1 The colour of different protective coverings

Protective coverings	*L*	*a*	*b*	Chroma	Hue
White shade net	89.94	1.10	3.60	3.76	73.01
Silver shade net	60.40	1.12	4.63	4.76	76.40
Green shade net	27.64	– 10.67	– 3.16	11.13	196.50
Red shade net	27.01	28.77	3.98	29.04	7.88
Stainless steel screen net	37.46	0.91	2.36	2.53	68.91

Results

Seedling height and internodal length

In both the rootstock seedlings (rough lemon and Carrizo citrange) under study, the highest seedling height was recorded in white net (Table 2). In rough lemon, the highest final seedling height of 51.0 cm in the month of September, 2016 was recorded in white net which was closely followed by 48.2 cm final seedling height under red net. The green net resulted in 44.4 cm final seedling height in rough lemon which was lower than final seedling height in

Table 2 Effect of different shade nets on seedling height, internodal length and leaf area of rough lemon and Carrizo Citrange seedlings

Protective coverings	Seedling height (cm)		Internodal length (cm)		Leaf area (cm^2)	
	Rough lemon	Carrizo citrange	Rough lemon	Carrizo citrange	Rough lemon	Carrizo citrange
Open conditions	42.0 ± 0.2^{d}	50.1 ± 0.4^{d}	1.3 ± 0.04^{bc}	1.2 ± 0.09^{a}	6.0 ± 0.6^{c}	6.6 ± 0.3^{c}
White shade net	51.0 ± 0.2^{a}	80.3 ± 0.6^{a}	1.5 ± 0.06^{ab}	1.4 ± 0.07^{a}	13.8 ± 0.9^{b}	9.6 ± 0.5^{ab}
Silver shade net	48.1 ± 0.4^{b}	73.4 ± 0.3^{b}	1.4 ± 0.04^{bc}	1.3 ± 0.04^{a}	14.9 ± 0.9^{ab}	8.8 ± 0.9^{ab}
Green shade net	44.4 ± 0.3^{c}	63.1 ± 0.6^{c}	1.3 ± 0.06^{bc}	1.2 ± 0.09^{a}	15.6 ± 1.2^{ab}	9.4 ± 0.8^{ab}
Red shade net	48.2 ± 0.9^{b}	75.1 ± 1.6^{b}	1.6 ± 0.06^{a}	1.6 ± 0.06^{a}	17.0 ± 0.5^{a}	10.0 ± 0.5^{a}
Stainless steel screen net	40.5 ± 1.2^{d}	46.8 ± 1.2^{e}	1.3 ± 0.05^{c}	1.2 ± 0.09^{a}	14.1 ± 0.7^{ab}	8.4 ± 0.4^{b}
LSD (0.05)	2.03	2.80	0.16	NS	3.03	1.39

Means with same letters within columns do not differ significantly at $p \leq 0.05$

red and silver nets. In Carrizo citrange, the highest seedling height (80.3 cm) was also recorded under white shade net which was followed by the seedling height (75.1 cm) under red net. The seedling height in red net did not differ significantly ($p \leq 0.05$) with final seedling height in under silver net (Table 2). The red net resulted in 21 and 32% increase in internodal length in rough lemon and Carrizo citrange seedlings over open conditions. In rough lemon, the highest internodal length (1.6 cm) was recorded under red shade net (Table 2) and it did not differ significantly from internodal length under white shade net (1.5 cm). It was followed by internode length (1.4 cm) under silver shade net which did not differ from internodal length under green shade net and open conditions. Similarly, the highest internodal length in Carrizo citrange was also recorded under red shade net, but it did not differ significantly from the internodal lengths under other protective coverings. After red net, white (12 and 15%), silver (8 and 14%) and green net (1 and 5%) also increased the internodal length in rough lemon and Carrizo citrnage, respectively.

Leaf area

Leaf area is a useful growth parameter as it depicts the dry matter producing capacity of a crop as utilization of intercepted radiation and photosynthesis. The highest leaf area in rough lemon was recorded in red shade net (17.0 cm^2) which did not differ significantly from leaf area under green shade net, silver shade net and steel mesh (Table 2). In Carrizo citrange also the highest leaf area (10.0 cm^2) was recorded in red shade net, which did not significantly differ from leaf area in white, green and silver shade net house. The red net resulted in the highest increase in leaf area (184 and 51%) in rough lemon and Carrizo citrange seedlings over open conditions (Table 2). All the other covering materials also resulted in increase in leaf area: in rough lemon seedlings, green (160%), silver (148%), steel mesh (136%) and white nets (130%) resulted in significant ($p \leq 0.05$) increase in leaf area. Similarly, the leaf area was also increased significantly by the white (47%), green (42%), silver (33%) and steel mesh (28%) in Carrizo citrange seedlings.

Seedling diameter

The seedling diameter is a very important nursery character for the rootstock seedlings as it directly influences the proportion of buddable seedlings and budding success. In both the rootstock seedlings, highest stem diameter was recorded in open conditions at all the data intervals (Fig. 1a, b). In

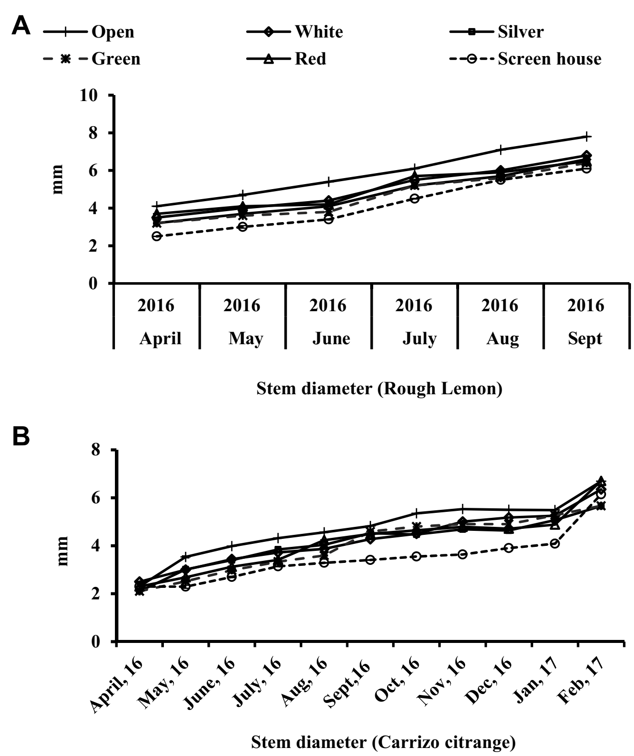

Fig. 1 Effect of different protective coverings on stem diameter (mm) of rough lemon (**a**) and Carrizo citrange (**b**) seedlings. The vertical bars represent standard error and are not visible if the values are very small

rough lemon, the highest stem diameter at the time of budding operation during September, 2016 was recorded in open conditions (7.8 mm) followed by stem diameter under white net (6.8 mm). The stem diameter in red, green and silver nets did not differ significantly ($p \leq 0.05$) with the final stem diameter recorded under white net. In Carrizo citrange also the highest final stem diameter (6.7 mm) was recorded in open conditions which did not differ significantly from stem diameter under red shade net, white net and stainless steel mesh. In rough lemon, white net resulted in minimum decrease (12.8%) in stem diameter over open conditions and it did not differ significantly for the final stem diameter under red, green and silver nets. In Carrizo citrange, as discussed earlier the maximum seedling diameter was also recorded in open conditions which did not differ significantly from the stem diameter under red, white and steel mesh. while significant reduction (14.9%) was recorded in stem diameter of Carrizo citrange seedlings under green and silver nets.

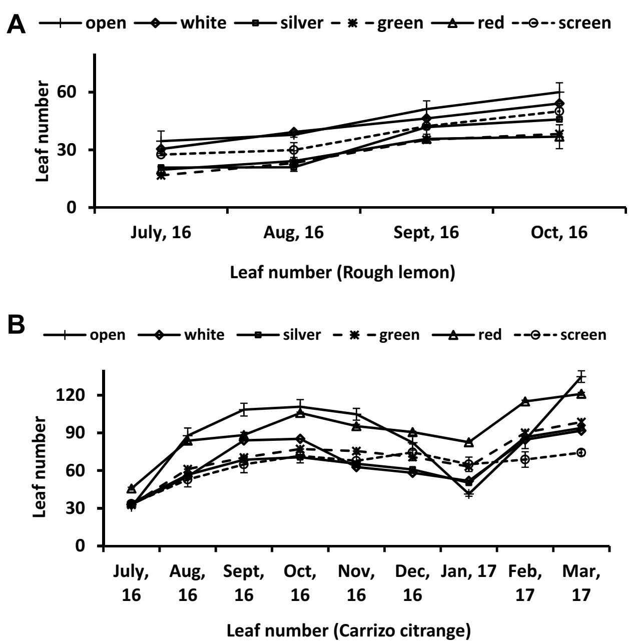

Fig. 2 Effect of different protective coverings on leaf number of rough lemon (**a**) and Carrizo citrange (**b**) seedlings. The vertical bars represent standard error and are not visible if the values are very small

Leaf number

In rough lemon, finally the highest leaf number (60) before the budding operation was found in open conditions which did not differ significantly ($p \leq 0.05$) with the number of leaves in rough lemon seedlings under white net and stainless steel screen net (Fig. 2a). In Carrizo citrange, also the final number of leaves was highest (134.8) in open conditions. It was followed by number of leaves (121.1) under red net house (Fig. 2b). In Carrizo citrange seedlings, the final leaf number under green shade net (98.6) did not differ from the leaf number under silver and white nets. Besides, the leaf number decreased during winters in Carrizo citrange as it is a deciduous rootstock, but there was not complete leaf fall in the winters. The lowest leaf number during the coldest month January, 2017 was recorded in open conditions (41.4) while the highest under red net (82.6), and the leaf number under rest of the protective nets (steel mesh, white, green and silver) did not differ significantly during January for Carrizo citrange.

Shoot and root dry weight; and root-shoot ratio

In rough lemon, the maximum shoot dry weight (11.0 g) was noted in open conditions which did not differ significantly ($p \leq 0.05$) from the shoot dry weight under white shade net house (Table 3). However, around 31% reduction was recorded in shoot dry weight in red, green, silver and steel mesh over open conditions, whereas in Carrizo citrange, the shoot dry weight increased in red (11%), white (5%) and green (3%) nets and decreased in silver (11%) and steel mesh (31%) over open conditions. Besides, there was significant reduction in root dry weight under the different protective coverings over

Table 3 Effect of shade nets on the dry weight and root to shoot ratio in rough lemon and carrizo citrange

Protective coverings	Rough Lemon			Carrizo citrange		
	Shoot dry weight	Root dry weight	Root to Shoot ratio	Shoot dry weight	Root dry weight	Root to Shoot ratio
Open conditions	11.0 ± 0.7^{a}	4.7 ± 0.8^{a}	0.43 ± 0.1^{ab}	10.9 ± 1.1^{a}	5.9 ± 0.1^{a}	0.55 ± 0.1^{a}
White shade net	10.5 ± 1.1^{a}	4.7 ± 0.6^{a}	0.45 ± 0.2^{ab}	11.5 ± 0.7^{a}	4.3 ± 0.1^{c}	0.38 ± 0.02^{c}
Silver shade net	7.5 ± 0.2^{b}	2.8 ± 0.04^{bc}	0.38 ± 0.2^{ab}	9.7 ± 0.9^{ab}	4.1 ± 0.2^{cd}	0.43 ± 0.1^{bc}
Green shade net	7.6 ± 0.2^{b}	3.5 ± 0.5^{abc}	0.46 ± 0.1^{ab}	11.2 ± 0.7^{a}	4.4 ± 0.2^{c}	0.39 ± 0.02^{bc}
Red shade net	7.5 ± 0.8^{b}	4.0 ± 0.8^{ab}	0.53 ± 0.1^{a}	12.0 ± 0.9^{a}	4.9 ± 0.2^{b}	0.41 ± 0.02^{bc}
Stainless steel screen net	7.6 ± 0.5^{b}	2.1 ± 0.2^{c}	0.28 ± 0.04^{b}	7.6 ± 0.5^{b}	3.8 ± 0.1^{d}	0.51 ± 0.03^{ab}
LSD (0.05)	2.05	1.77	0.18	2.56	0.46	0.13

Means with same letters within columns do not differ significantly at $p \leq 0.05$

open conditions. In rough lemon, in both open and white shade nets, 4.7 g root dry weight was recorded which did not significantly differ from root dry weight in red and green shade net houses. In Carrizo citrange also the maximum root weight (5.9 g) and root-shoot ratio (0.55) was recorded in open conditions.

Root growth

In rough lemon and Carrizo citrange rootstocks, the length of tap root did not differ significantly under all the nets (Table 4 and 5). The photoselective nets had a significant effect on root diameter and secondary root number in rough lemon. In Carrizo citrange, there was no significant ($p \leq 0.05$) effect of treatments on root diameter and number of secondary roots (Table 5). In rough lemon, the highest tap root diameter (10.6 mm) was also recorded in open conditions. It was followed by root diameter under red net (8.5 mm) which was on a par ($p \leq 0.05$) with root diameter under white, silver and green nets (Table 4). Highest secondary root number (53.0) was recorded in screen net house which was on a par ($p \leq 0.05$) with the root number in open conditions. It was followed by 36.8 secondary roots under red net house which did not significantly differ from secondary roots in green net.

Spad units

The variation in spad units did not show a specific trend. In the rough lemon leaves, the highest spad values were recorded under green shade net followed by screen house during July (Fig. 3a). Similarly, spad value at the time of budding operation in September was maximum under green shade net (67.1 spad units) followed by silver shade net (56.4 spad units). During, November to March highest spad units were recorded under silver net and it did not differ from the spad units under green net during March and April. In Carrizo citrange. during July to August the spad values under green, red and steel mesh was high and did not differ with each other. In September and October, the spad values did not differ significantly ($p \leq 0.05$) under different nets. In spring season (February to April), highest spad values were recorded under red shade net and it did not differ significantly from spad values under silver and green nets.

Photosynthetically active radiation and photosynthetic rate

A significant reduction in photosynthetically active radiation (PAR) was recorded under shade nets in comparison to open field conditions (Fig. 4a, b). Red shade net registered significantly higher PAR during April and May, 2017. It was

Table 4 Effect of different shade nets on root growth of rough lemon

Protective coverings	Tap root length	Tap root diameter	Number of secondary roots
Open conditions	33.0 ± 4.5^{a}	10.6 ± 0.1^{a}	50.2 ± 7.3^{ab}
White shade net	25.3 ± 1.9^{a}	8.2 ± 0.3^{b}	32.0 ± 5.4^{c}
Silver shade net	21.4 ± 2.4^{a}	8.0 ± 0.1^{b}	29.7 ± 3.2^{c}
Green shade net	24.6 ± 2.0^{a}	7.9 ± 0.2^{b}	36.5 ± 3.0^{bc}
Red shade net	20.4 ± 5.4^{a}	8.5 ± 0.3^{b}	36.8 ± 4.2^{bc}
Stainless steel screen net	27.1 ± 2.2^{a}	6.8 ± 0.3^{c}	53.0 ± 5.3^{a}
LSD (0.05)	NS	0.71	15.20

Means with same letters within columns do not differ significantly at $p \leq 0.05$

Table 5 Effect of different shade nets on growth of Carrizo citrange

Protective coverings	Tap root length	Tap root diameter	Number of secondary roots
Open conditions	27.2 ± 3.9^{a}	8.4 ± 0.3^{a}	47.8 ± 0.1^{a}
White shade net	26.2 ± 0.7^{a}	8.1 ± 0.4^{a}	53.3 ± 0.1^{a}
Silver shade net	27.6 ± 2.2^{a}	8.0 ± 0.2^{a}	46.3 ± 0.2^{a}
Green shade net	26.4 ± 0.9^{a}	8.0 ± 0.1^{a}	45.5 ± 0.1^{a}
Red shade net	26.1 ± 4.6^{a}	7.9 ± 0.2^{a}	52.7 ± 0.2^{a}
Stainless steel screen net	35.0 ± 5.8^{a}	8.1 ± 0.8^{a}	48.2 ± 0.1^{a}
LSD (0.05)	NS	NS	NS

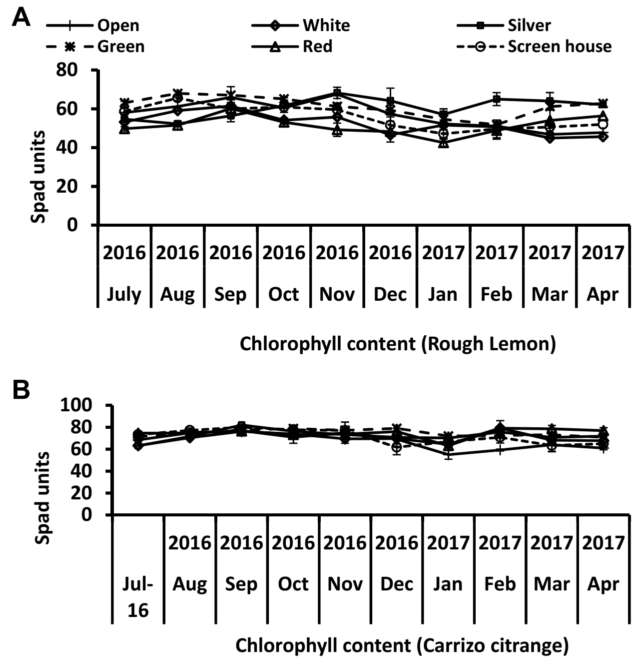

Fig. 3 Effect of different protective coverings on spad values in rough lemon (**a**) and Carrizo citrange (**b**) leaves. The vertical bars represent standard error and are not visible if the values are very small

followed by PAR values under green, silver and white shade nets. The open field conditions showed lower photosynthesis rate than the shaded conditions which may be due to shading effect of different protective covering. Irrespective of the treatments, the photosynthetic rate increased progressively up to the month of December, 2016 and thereafter it declined up to May, 2017 (Fig. 4c, d). The maximum photosynthetic rates in rough lemon were recorded under red shade net (Fig. 4c). In red shade net, the photosynthetic rate during the months of September, 2016 and May, 2017 were 7.31 and 3.71 μmol m^{-2} s^{-1}, respectively. The photosynthetic rate in Carrizo citrange in the month of July, 2016 was highest under red shade net (5.15 μmol m^{-2} s^{-1}) which did not differ with the photosynthetic rate in open conditions, while the lowest photosynthetic rate (5.04 μmol m^{-2} s^{-1}) was recorded in green shade net (Fig. 4d). During May, 2017, the highest photosynthetic rate was also recorded under red shade net (3.78 μmol m^{-2} s^{-1}) which was on a par ($p \leq 0.05$) with the photosynthetic rates recorded under white and open conditions, respectively.

Stomatal conductance

The highest stomatal conductance in rough lemon at most of the intervals was recorded under red shade net and/ or white net (Fig. 5). In the month of July 2016, the highest

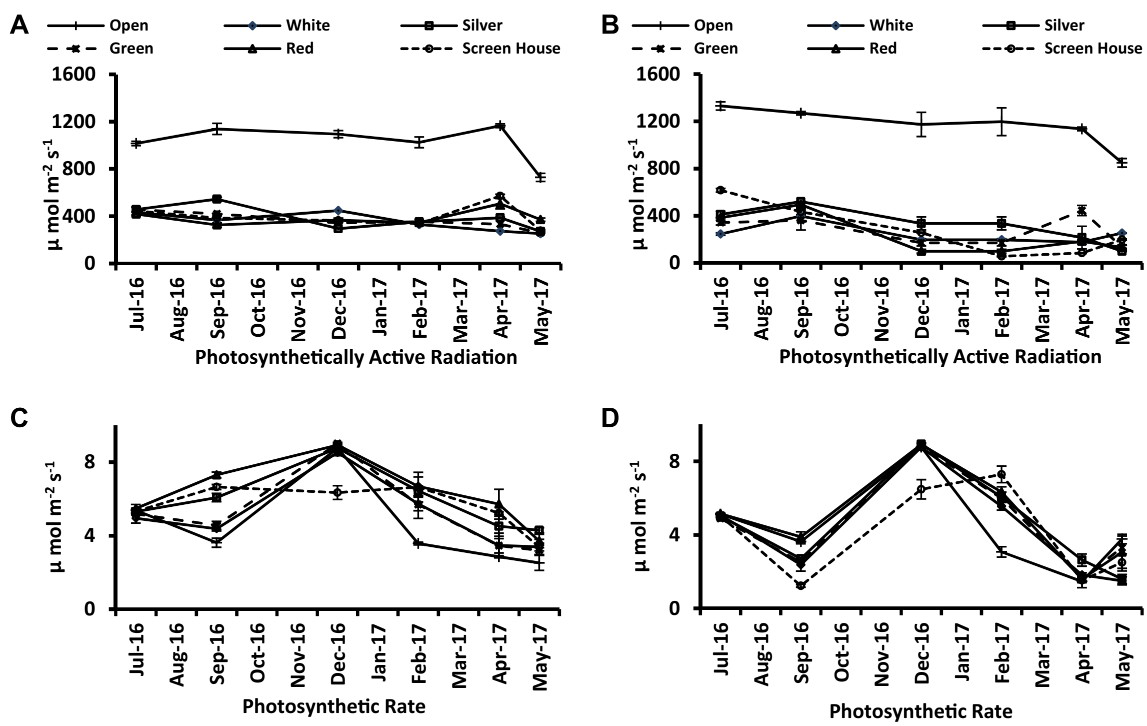

Fig. 4 Effect of different protective coverings on photosynthetically active radiation in rough lemon (**a**) and Carrizo citrange (**b**) seedlings; and stomatal conductance in rough lemon (**c**) and Carrizo citrange (**d**) seedlings. The vertical bars represent standard error and are not visible if the values are very small

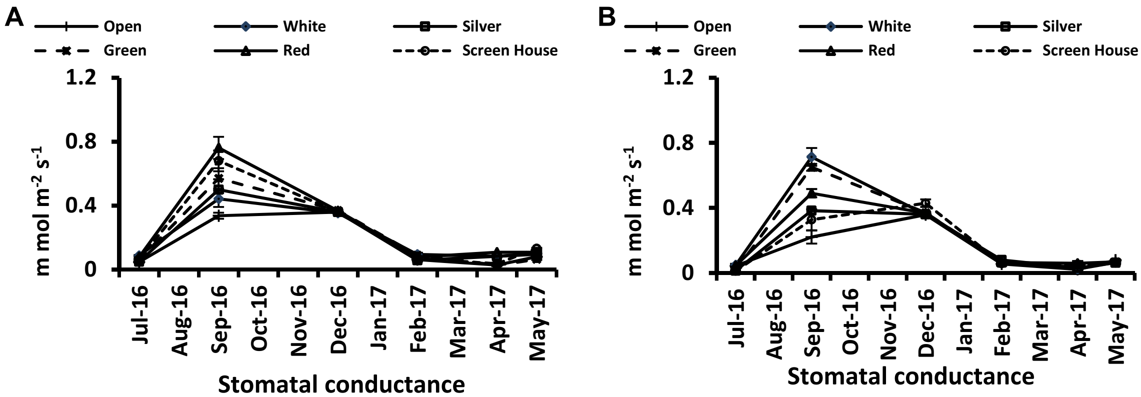

Fig. 5 Effect of different protective coverings on stomatal conductance in rough lemon (**a**) and Carrizo citrange (**b**) seedlings. The vertical bars represent standard error and are not visible if the values are very small

stomatal conductance was recorded in white shade net (0.09 m mol m^2 s^{-1}) which did not differ significantly from stomatal conductance under red shade net. The minimum stomatal conductance (0.05 and 0.03 m mol m^2s^{-1}) was observed in open conditions, whereas during the month of May, 2017 the stomatal conductance was recorded to be the highest under screen net (0.13 m mol m^{-2} s^{-1}) which did not differ significantly from the stomatal conductance under red net. Similarly, in Carrizo citrange, maximum stomatal conductance (0.05 m mol m^{-2} s^{-1}) during the month of July, 2016 was exhibited under the white shade net which did not differ significantly from the stomatal conductance under red shade net and open conditions (Fig. 5), while during the months of February, April and May the shade nets had no significant effect on the stomatal conductance of Carrizo citrange.

Nutrient uptake

The highest nitrogen (3.51 and 3.99%, respectively) and phosphorus (0.27 and 0.39%, respectively) in the leaves of rough lemon and Carrizo citrange (Fig. 6a, b) was observed under red shade net. The highest potassium levels in rough lemon were also recorded under screen shade net (1.30%) which did not differ from potassium levels in red net (1.20%). The highest potassium content in Carrizo citrange seedlings was also under green shade net (1.30%) which did not significantly differ from potassium content in the red net. In both the rootstock seedlings, the highest zinc content was also recorded in red shade net (106.27 and 91.60 ppm, respectively), whereas in rough lemon the highest iron content was recorded in white net (179.40 ppm) which was closely followed by iron content under red net (164.80 ppm). The highest iron content in Carrizo citrange was in red shade net (191.73 ppm) followed by open conditions (186.40 ppm), while the lowest content of iron was reported in silver shade net. The increase in nitrogen levels could be attributed to the increase of the spectral components beneficial for plant growth and enhanced the nitrogen content (Fig. 6).

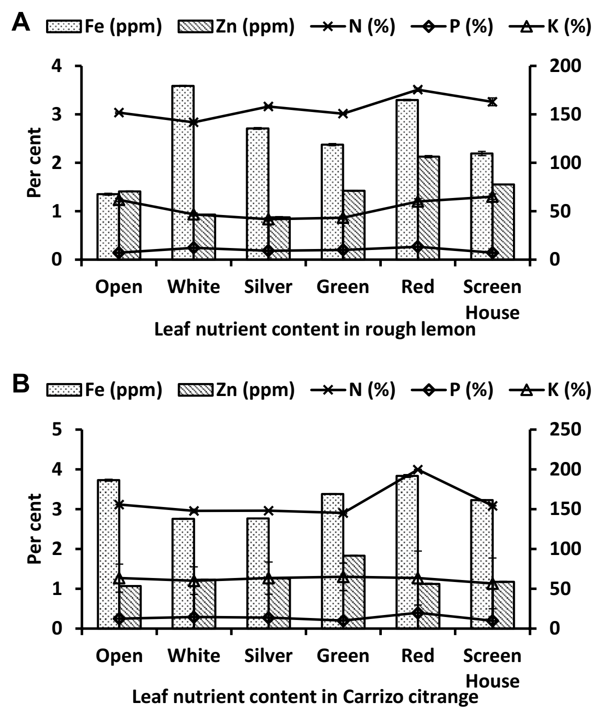

Fig. 6 Effect of different protective coverings on nutrient levels in rough lemon (**a**) and Carrizo citrange (**b**) seedlings. The vertical bars represent standard error and are not visible if the values are very small

Buddable rootstock seedlings and budding success

The proportion of rough lemon seedlings which attained the desirable thickness (> 6.5 mm) for budding operation in September, 2016 (Table 6) was higher in open conditions

Table 6 Effect of different shade nets on proportion of buddable rootstock seedlings (%) and budding success (%)

Protective coverings	Buddable rootstock seedlings (%)			Budding success (%)	
	Rough lemon	Carrizo citrange		Rough Lemon	Carrizo citrange
	September, 2016	September, 2016	March, 2017		
Open conditions	91.0[a]	36.3[a]	86.3[a]	81.0 ± 0.6[c]	57.7 ± 0.9[c]
White shade net	90.0[a]	22.0[cd]	72.0[cd]	83.7 ± 0.3[b]	62.0 ± 0.6[b]
Silver shade net	81.7[d]	23.66[c]	73.7[c]	83.7 ± 0.9[b]	58.0 ± 0.6[c]
Green shade net	72.7[c]	30.3[b]	80.3[b]	82.7 ± 0.3[bc]	53.7 ± 1.7[d]
Red shade net	82.0[b]	23.0[c]	73.0[cd]	86.0 ± 0.6[a]	68.7 ± 0.7[a]
Stainless steel screen net	37[d]	19.3[d]	69.0[d]	82.3 ± 0.9[bc]	57.0 ± 0.6[c]
LSD (0.05)	3.3	2.84	4.0	2.22	2.18

Means with same letters within columns do not differ significantly at $p \leq 0.05$

(91%) which was closely followed by white shade net (90%). This was further followed by the proportion of buddable rough lemon seedlings under red shade net by (82%). In Carrizo citrange, the proportion of buddable seedlings at the time of budding operation of rough lemon (September, 2016) was much lower as compared to rough lemon plants (Table 6). Considering the stem diameter, the budding operation in Carrizo citrange was performed in March, 2017. At this time, highest proportion of buddable Carrizo citrange seedlings was also recorded in open conditions (86.3%) followed by seedlings under Green shade net (80.33%). In rough lemon, around 10% higher proportion buddable seedlings were recorded in open conditions than red, silver and white nets, whereas the proportion of buddable seedlings in green net was 20% lower than the open conditions. In Carrizo citrange, also the proportion of buddable seedlings was significantly higher in open than all the other nets.

In rough lemon, the highest budding success (Table 6) was recorded under red shade net (86%), which was closely followed by budding success under white net (83.67%). The budding success under white net was on a par ($p \leq 0.05$) with budding success under silver and green nets. In open conditions, 81 per cent budding success was recorded which was on a par with the budding success under steel mesh. Similarly, in Carrizo citrange also the highest budding success was recorded under red shade net (68.67%) which was followed by 62 per cent budding success under white shade net. In the silver net, 58 per cent budding success was recorded in Carrizo citrange which did not differ significantly ($p \leq 0.05$) with the budding success in open and screen house conditions.

Buddling growth

Buddling growth of the budded plants is the most important criteria for the nursery plants. The highest sprout lengths during August, 2017, in Kinnow (57.83 cm) and Daisy mandarin saplings (34.77 cm) were recorded in red net followed by green net and white net. Similarly, highest sprout diameter and leaf number were also recorded under red net followed by white net, while the minimum sprout length, diameter and number of leaves were recorded in open conditions (Table 7).

Table 7 Effect of different protective coverings on final sprout length (cm), sprout diameter (mm) and leaf number in Kinnow and Daisy mandarin saplings

Protective coverings	Sprout length (cm)		Sprout diameter (mm)		Leaf number	
	Kinnow	Daisy	Kinnow	Daisy	Kinnow	Daisy
Open conditions	39.8 ± 0.9[d]	25.1 ± 0.5[c]	5.3 ± 0.04[c]	3.8 ± 0.02[ab]	52.7 ± 1.3[cd]	32.3 ± 0.7[b]
White shade net	48.5 ± 0.6[c]	26.4 ± 1.2[c]	5.3 ± 0.06[c]	3.7 ± 0.03[b]	52.3 ± 3.2[cd]	26.0 ± 1.5[c]
Silver shade net	47.6 ± 0.3[c]	21.9 ± 0.5[d]	5.5 ± 0.06[b]	3.0 ± 0.10[d]	50.0 ± 2.0[d]	27.0 ± 1.7[c]
Green shade net	51.8 ± 1.2[b]	31.4 ± 3.3[b]	5.3 ± 0.11[c]	3.8 ± 0.29[ab]	67.0 ± 3.2[b]	36.0 ± 3.7[b]
Red shade net	57.8 ± 0.9[a]	34.8 ± 1.2[a]	5.7 ± 0.05[a]	3.9 ± 0.03[a]	92.3 ± 1.8[a]	49.0 ± 1.2[a]
Stainless steel screen net	47.7 ± 1.2[c]	24.5 ± 1.2[cd]	5.3 ± 0.02[c]	3.3 ± 0.06[c]	59.3 ± 2.4[bc]	32.0 ± 2.3[b]
LSD (0.05)	2.68	3.04	0.15	0.16	8.16	4.67

Means with same letters within columns do not differ significantly at $p \leq 0.05$

Principal component analysis

Rough lemon

The principal component analysis (PCA) showed that 90.97% of the total variability observed for the different plant characters under different protective coverings for rough lemon was explained by the first three components i.e., PC1, PC2 and PC3 which accounted for 47.62%, 26.41% and 16.93% of the total variability, respectively. The first two principal components contributing 74.04% of the total variability were plotted to categorize the variables and to observe the relationship between clusters (Fig. 7). Each protective net was plotted in accordance with the score of its principal components for the first two principal components. Plant height of rough lemon seedlings was positively correlated to internodal length, budding success, leaf area, leaf phosphorus and iron levels. The plant diameter which is an important character for nursery production was positively correlated to leaf number, shoot and root dry weight and root diameter. Budding success was positively correlated with Kinnow mandarin sprout length, diameter and leaf number. The biplot shows that the plants under red net had better height, internodal length and budding success in rough lemon seedlings. Besides, higher sprout length, diameter and leaf number of Kinnow mandarin budded on rough lemon were also recorded under red net, while in open condition, higher shoot and root diameter, shoot and root dry weight, leaf number and root length were recorded in rough lemon seedlings. Highest buddable seedlings were recorded in white net. Better growth of rough lemon and Kinnow mandarin saplings was recorded in red net. The white and silver net also performed better than other nets.

Carrizo citrange

The biplot pertaining to PCA for plant growth and nutrient uptake in Carrizo citrange seedlings latter budded with Daisy mandarin under the different protective coverings is presented in Fig. 8. The first three PCs accounted 39.17% (PC1), 28.48% (PC2) and 17.44% (PC3) of the total variability, respectively. The first two principal components, PC1 and PC2, accounted for 67.65 per cent cumulative variation from the data sets. It was found that among the different variables, plant diameter (4.51%), internodal length (8.00%), shoot weight (8.12%), root length (5.3%), nitrogen (8.4%), phosphorus (9.7%), budding success (8.62%), sprout length (7.62%) and sprout dimeter (6.1%) contribute maximum to the PC1. In PC2, maximum contribution (14.5%) is from root diameter followed by root weight (12.7%), leaf area (12.4%) and buddable seedlings (12%). The Carrizo seedlings under red net had better seedling diameter, internodal length, leaf area, leaf number, shoot dry weight and budding success. Higher sprout growth, sprout diameter and sprout leaf number of Daisy mandarin budded on Carrizo citrange were also recorded under red net. Higher plant height and leaf area were recorded under white net, whereas root diameter and root shoot ratio in open conditions. Better growth of Carrizo citrange seedlings and subsequently the Daisy mandarin was recorded under red net. The white net also performed better than other nets. The Daisy sprout length,

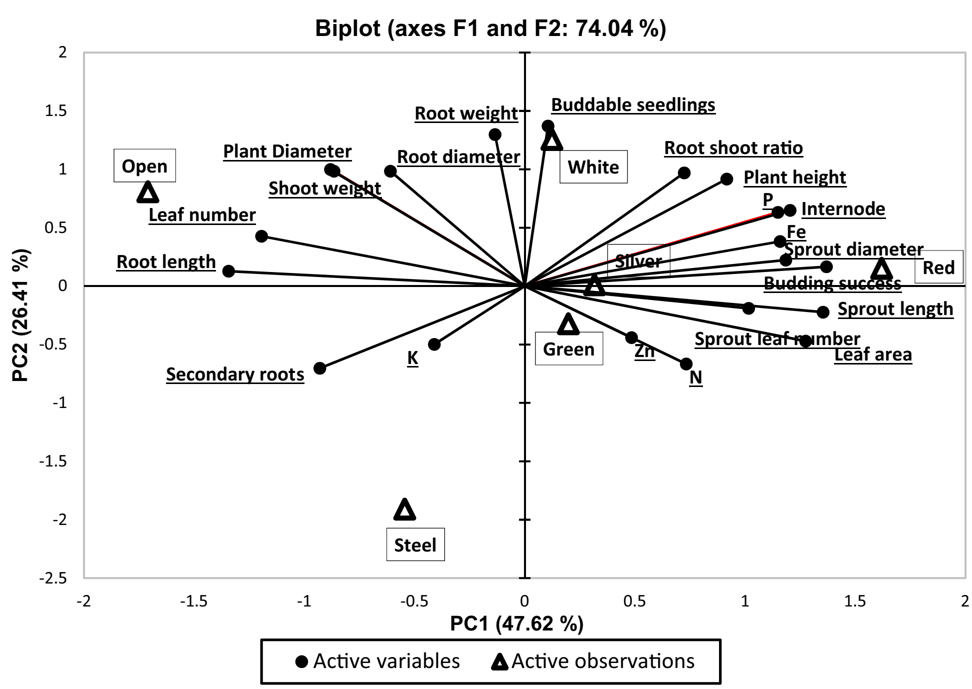

Fig. 7 Principal component analysis for growth characters, nutrient uptake and buddability of rough lemon

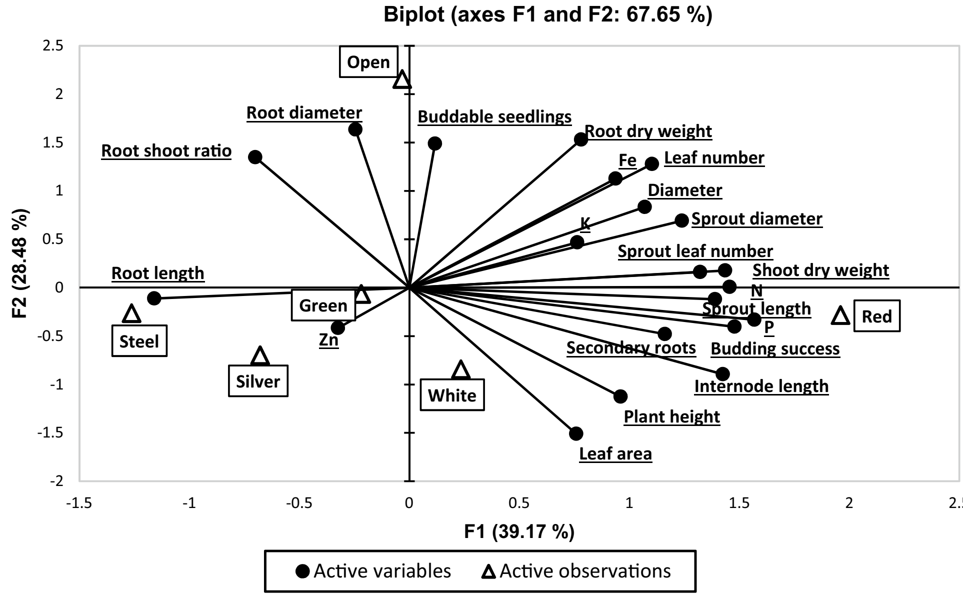

Fig. 8 Principal component analysis for growth characters, nutrient uptake and buddability of Carrizo citrange

sprout leaf number and sprout diameter were positively correlated with each other and budding success.

Discussion

Seedling growth

In both the rootstock seedlings (rough lemon and Carrizo citrange) under study, highest seedling height was recorded in white net (Table 2). The white net resulted in 21.5 and 60.2% increase in final seedling height over the open conditions in rough lemon and Carrizo citrange rootstock seedlings, respectively. The seedling height in white net was followed by seedling height in red net which was 12.8 and 6.9% higher in rough lemon and Carrizo citrange rootstocks seedlings, respectively, in comparison to open conditions. The commonly used green net increased the seedling height only by 5.8 and 27.4% in both rough lemon and Carrizo citrange rootstock seedlings, respectively. While studying the effect of different shade net colours in bell pepper, Ayala et al. (2015) found that shading resulted in an increase in plant height. Further, the black, beige, red and green nets resulted in 23.1–33.0% increase in plant height than the open field. Márquez-Quiroz et al. (2014) also recorded an increase in final plant height of cherry tomato under 30% shade than open field conditions due to reduced light. The higher exposure to light retards stem elongation by reducing the gibberellin supply to the actively growing regions of plants. The higher plants have photoreceptors for blue, green and UV light (phototropins and cryptochrome) and R/FR receptors (phytochromes). High *R*/ FR ratio leads to reduction in plant height and increase plant compactness (Mata and Botto 2011), whereas lower *R*/FR ratios lead to increase in plant height, apical dominance and reduction in branching. Lower *R*/FR ratio under shade nets may be responsible for the higher plant height under netting over control as reported by Arthurs et al. (2013). In the present studies, higher photosynthetically active radiation (Fig. 4) and light intensity (data not presented) were recorded in open conditions. The photo-assimilates in the shade are redirected away from the plant parts owing to storage and resource acquisition for the purpose of the shoot elongation at the cost of development of the leaf (Brutnell 2006). Gaurav et al. (2016) found that the ornamental plant *Dracaena fragrans* grown under white and red nets exhibited maximum height over green and black shade nets. In the present studies, higher number of leaves was recorded in open conditions than the shade nets (Fig. 2). The rate of the shoot elongation increases as the depth of the shade increase; hence it leads the leaves to strive and reach the tree boundary for the sunnier positions under the shade nets. When the plants already growing in open conditions are shifted to shade nets, it results in development of longer petioles and internodes with increased growth. The plants also produced lesser dry matter and the shoots retained higher photosynthates resulting in reduction of leaf and root growth (Brutnell 2006). However in the present studies, the leaf area under the shade nets was higher than the open conditions (Table 2). The production of thinner and larger leaves slows down the development of the chloroplast and the leaf, but improves the apical dominance which may be due to higher gibberellin synthesis under shade (Toyomatsu et al. 1998).

The higher stem diameter in open field conditions is in conformity with the results obtained by Gilbert et al. (2013), who recorded maximum stem diameter in *Eucalyptus* hybrid plants in open conditions and red shade net among the aluminized (silver) net, red net, green net, blue net and open conditions. Similarly, Costa et al. (2010) observed higher stem diameter of *Ocimum selloi* plants in open conditions, but coloured shade nets had no significant effect on the stem diameter of the plants. The stem is mostly made up by the vascular tissues and stem diameter has the direct correlation to the transport capacity of carbohydrates and water and indirectly with the capacity to store these metabolites. The higher rootstock seedling height under white net (Table 2) was compromised with the stem girth, thereby leading to total decrease in the stem girth as compared to the open conditions, as the assimilates might have been incorporated towards the height increase as compared to the increase in the girth of the rootstocks.

The highest leaf number in open conditions in both the rootstock seedlings may be due to higher photosynthetically active radiation (Fig. 4) available in open conditions as compared to shade nets. Similar results were reported in *Spinacea oleracea* where the highest number of leaves were recorded in open conditions as compared to red, back, green and white coloured shade nets (Meena et al. 2015). In rough lemon, the number of leaves under white net and steel mesh was on par ($p \leq 0.05$) with the number of leaves in open conditions, whereas the leaf number in Carrizo citrange in open conditions was closely followed by leaf number under red net. The differences in the two rootstock seedlings for the number of leaves under different nets may be due to the genotypic factors. The significantly higher number of leaves obtained in Carrizo citrange seedlings under red net over other nets may be due to spectral effect of the red shade net that influences the plant growth. Damodar (2014) also reported significantly higher leaf number with red coloured nets due to higher selectivity of red coloured shade net than the dark nets (black, blue etc.) which results in absorption of major portion of light spectra.

The larger leaf area of the plants under shade was possibly due to adaptive mechanism of the plants for receiving light for photosynthesis as the rootstock seedlings under shade also had lower number of leaves than the open conditions (Fig. 2). Tinyane et al. (2013) have observed higher leaf area, stem elongation and leaf area index under low-intensity radiation. Similarly, Ilic et al. (2015) reported that red and pearl-coloured photoselective coverings lead to significant increase in leaf area, as compared to the parameter values recorded under the black and blue photoselective coverings. The red nets stimulated the growth rate, vigour and internodal length in Pittosporum (Oren-Shamir et al. 2001; Shahak et al. 2008). Red light in many plant species increased the starch accumulation by photo-assimilates' translocation inhibition to the other tissues and hence the red light proves to be important for photosynthetic apparatus development (Kasperbauer and Hamilton 1984).

The higher plant height under red/white shade nets and higher stem diameter in open conditions may have resulted in higher shoot dry weight in these growing conditions. In rough lemon, higher plant diameter, root diameter and leaf number may have resulted in higher dry weights in open condition (Fig. 7). The morphogenesis and development are related to changes in composition of the light spectrum while biomass production and the growth of the plant are related to the radiation intensity (Stuefer and Huber 1998).

Root growth

The photoselective netted and unnetted trees have been reported to show similar effect on root length in young orange trees (Zhou et al. 2018). In citrus, peak root growth occurs in summers (Bevington and Castle 1985); the higher root diameter and secondary roots in open conditions in the present studies could be attributed to the higher light intensity and temperatures which can be justified from the more favourable temperature values in the open conditions for root length development (Supplementary Fig. 3). Zhou et al. (2018) also recorded higher average root number and root density in open conditions in comparison to shade nets up to 80 cm root depth in orange trees grown on sour orange rootstock. The higher root diameter in open conditions can also be justified from the relationship between the shoot and root diameter as reported in *Pinus radiata* (Pretzsch et al. 2012). Noordwijk et al. (2004) also found a consistent relationship between stem and proximal root diameter. The nets had no significant effect on the secondary root number in Carrizo citrange, but significantly ($p \leq 0.05$) higher secondary root number was recorded in rough lemon in open conditions which may also be due to genotypes × environment interactions.

Physiological parameters

The higher PAR under red nets (Fig. 4) may be due to higher transmission of light under red shade net and more selectivity for light flux required for photosynthesis over green and blue shade nets. The green and blue nets transmit more light in green and blue regions, respectively, and absorb light in shorter and longer wavelengths (Oren-Shamir et al. 2001). The red shade nets work as spectral filters which absorb radiation below a specific wavelength range and transmit the radiation above this wavelength. The yellow and red shade nets absorb light in ultraviolet and blue regions to equal extent (Shahak et al. 2016). Shahak et al. (2004b) reported that the direct light element was fundamentally wavelength neutral, i.e. the spectrally altered light is fully (Yellow, Red and Pearl nets) or mostly (Blue net) scattered. Oren-Shamir et al. (2001) also illustrated that the relative content of dispersed over total PAR was higher under colour shade nets in comparison to natural light or under black net. The lower PAR transmittance was observed in black shade net, blue shade net and thermos-reflective screens (Al-Helal and Abdel-Ghany 2010). Light quality alteration is an innovation for sustainable production in fruit crops (Bastías et al. 2012). Plants in terms of their development and growth significantly react to alterations in light quality along with the photosynthetic active radiation which provides carbon and energy required for sustainable growth of plants. The metabolic processes in the plants are regulated by pigment-based specific photoreceptors which include far-red (FR) and red (R) light-absorbing phytochromes and blue and ultraviolet light-absorbing phototropins and cryptochromes (Smith 2000). Besides, the water deficit was not established under shade net due to lower air and leaf temperatures (Supplementary Fig. 2 and 3) and higher stomatal conductance (Fig. 5). Coloured shade nets modify light transmission which influences chlorophyll levels and subsequently the spad units (Fig. 3b). Plants receive lower light intensities under shade and maintain higher chlorophyll over plants grown in open conditions. The higher spad values in the plants grown under shade could also be attributed to the higher scattered radiation needed for production of carbohydrates for plant growth (Ilic et al. 2017).

The higher photosynthetic rates observed under red shade net may be due to higher light-use efficiency for photosynthesis with red light. Besides, the improvement in the photosynthesic rate and stomatal conductance may be due to lower temperatures (Supplementary Fig. 3) under shade nets. Shahak et al. (2004a) reported increase in photosynthesis and stomatal conductance due to cooling of leaves of apple trees under shade nets, however, with almost 30% reduction in total PAR. Higher mid-day stem water potential was observed under red net over open conditions, but the best stem water potentials were recorded in pearl, grey and blue-coloured shade nets. The significant decrease in leaf transpiration and leaf temperature without any alterations in net photosynthesis is possible due to moderate levels of shade. There is a linear relationship between net photosynthesis and stomatal conductance under the shade net conditions. The mesophyll or biochemical factors other than stomatal factors can reduce the photosynthesis and enhance internal CO_2 concentration with increase in shade (Assmann 1988).

The higher stomatal conductance under red shade net (Fig. 5) may be due to the lower maximum temperatures and canopy temperatures (Supplementary Fig. 2 and 3) under the red net as discussed by Medina et al. (2002). Solar radiation is the major weather factor influenced by shade net which affects plant tissue temperatures, photosynthesis and transpiration. The coloured shade nets modify light in either the visible, ultra-violet or far-red spectral regions; the shade net also improved the relative content of scattered vs. direct light and absorbs radiation in the infrared range (Shahak et al. 2004b). All the shade-nets decreased temperature, light intensity and improved humidity (Gaurav et al. 2016). Relatively, higher light intensity in screen house can be attributed to the different material of the netting as compared to the HDPE shade nets.

Nutrient uptake

The increase in nitrogen levels could be attributed to the increase of the spectral components beneficial for plant growth and enhanced the nitrogen content (Fig. 6). Healy et al. (1998) have earlier reported highest leaf nitrogen concentration in the plants grown under bird guard, whereas Sinclair and Horie (1989) related higher leaf nitrogen content under birdguard canopy to higher radiation use efficiency due to reduction in respiration rate and/or root to shoot ratio. The lower incident radiation improves the radiation use efficiency due to low radiation flux on the lower canopy leaves which increases the canopy efficiency (Hammer and Wright 1994).

Buddable rootstock seedlings and budding success

In rough lemon, around 10% higher proportion of buddable seedlings was recorded in open conditions than red, white and silver nets (Table 6), whereas the proportion of buddable seedlings in green net was 20% lower than the open conditions. In Carrizo citrange, also the proportion of buddable seedlings was significantly ($p \leq 0.05$) higher in open conditions than the nets. The decrease in the proportion of buddable carrizo citrange seedlings was 7% for green, 15% for silver and red, and 17% white shade nets. This influence on the proportion of the buddable seedlings was due the effect of the different growing conditions on stem diameter (Fig. 1). The higher stem diameter in open conditions led to the higher proportion of buddable seedlings in open conditions. The higher budding success under red net might be due to congenial growth conditions viz. temperature, relative humidity, light intensity and sap flow in rootstocks under red net which is favoured for callusing and healing process. The higher temperatures and lower humidity might have resulted in lower budding success in open conditions. Under the shade nets the air temperatures were lower than ambient air temperatures (Supplementary Fig. 3). The shade nets alter light quality, wind speed and wind run to a varying extent which might affect the inside temperature and relative humidity. These changes affect respiration, transpiration, photosynthesis and plant growth (Shahak et al. 2004b). Shade nets reduce the heat stress over the crops (Elad et al. 2007). The temperatures in the enclosed shade nets were generally higher than outside during the daytime (Perez et al. 2006) and are lower during night. The lower light intensity under colour shade nets may be responsible for lower maximum temperatures under shade nets over control. In the present studies, higher relative humidity levels were recorded under the colour shade nets over open conditions (Supplementary Fig. 2). The air movement in the shade net house depends on the porosity, plant location, season and time of the day (Meena et al. 2015). In shade nets, lower wind speed causes lower evaporation losses which in turn results in lower loss of soil moisture preventing plant water stress. Higher relative humidity under shade nets over open conditions might be due to lesser entry of dry air from outside the shade net and higher transpiration by plants (Elad et al 2007).

Conclusions

The highest proportion of buddable seedlings was recorded in open conditions, but the highest budding success and better sapling growth were recorded in red shade net house. Improvement in photosynthesis and stomatal conductance was recorded in citrus plants under red shade net over the other shade nets and open conditions.

Author contribution statement HSB: Executed the research in field as a Master's Student, collected data, analysed the data, tabulated and written the MS. AT: Planning of research as a Supervisor, data analysis and writing of the manuscript and interpretation of results. HS: Helped in recording the agrometeorological and physiological data. NK: Helped in recording physiological data and interpretation of results.

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