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RESPONSE OF ROOTSTOCKS AND SOIL AGRO-TECHNIQUES TO REPLANT PROBLEM IN APPLE (*Malus × domestica* Borkh.)

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ABSTRACT

A study was conducted to assess the impact of soil agro-techniques and rootstocks on new apple plantation at an old declining apple orchard site. The study comprised of 20 treatments *viz.*, four apple rootstocks namely Seedling, Merton 793, MM.111 and M.7, and five soil agro-techniques i.e. soil fumigation with formaldehyde, PGPR (*Bacillus licheniformis* CK-1), biocontrol (*Trichoderma viride*), combined agro-techniques and untreated control. The rootstock of 'Merton 793', combined soil agro-techniques and their combination showed higher growth (height, leaf area, feathers and plant volume) and improved physiological activities (chlorophyll content, photosynthetic efficiency and chlorophyll fluorescence) as compared to the other rootstocks and untreated control under replant situations. These approaches can be effectively adopted to overcome the replant problem in apple orchards.

Keywords: Apple replant problem, biocontrol, growth, photosynthetic efficiency, rootstocks

INTRODUCTION

Apple (*Malus × domestica* Borkh.) is the major fruit crop grown in the temperate regions of the world and the economy of the farmers of these regions largely depends on apple cultivation. The apple plants complete their economic lifespan within 50 years and it is difficult to raise new plantations at older orchard sites because of replant problem. At present, apple replant problem is a major constraint in apple production in Western Himalayan region. The existing apple orchards in Himachal Pradesh and other North Western Himalayan states of India, planted somewhat fifty years ago, have already completed their lifespan and show the symptoms of declining productivity (Singh *et al.*, 2018). Due to the scarcity of land and limited crop choice for diversification in temperate regions, the orchardists are compelled to raise new apple plantation on old apple orchard sites, which often leads to the drastic economic losses due to the poor establishment and performance of new plantations on replant site (Singh *et al*., 2017). The plant growth and its physiological activities are adversely affected by replanting the same fruit crop at the older orchard sites due to replant disease or soil sickness problems (McKenry, 1999).

The plant photosynthetic organ is very sensitive to stress and may often be the primary position to suffer (Zhang *et al*., 2009). Chlorophyll fluorescence technique and photosynthetic pigment assessment are non-invasive tool in eco-physiological studies and have extensively been used to assess plant response to environmental stress (Sayed, 2003). There has been a substantial increase in the proportion of declining orchards year after year in Himachal Pradesh which needs to be addressed by developing suitable agro-techniques to combat the replant problem for better field survival rate and sustainable the productivity of apple (Singh *et al.*, 2020). The standardization of protocols of soil agro-techniques and rootstocks for replantation may provide a new lease of life to the declining apple orchards of the temperate regions. The present study was, therefore, aimed to assess the impact of rootstocks and soil agro-techniques on the replant problem in apple under North Western Himalayan conditions.

MATERIALS AND METHODS

The present investigation was carried out during the year 2015 and 2016 in plastic pots of 50 L capacity in the experimental field of Department of Fruit Science, Dr YS Parmar University of Horticulture and Forestry, Solan, Nauni, HP (India). The site is located at an elevation of 1250 m masl at 30° 51'N latitude and 76° 11'E longitude under rain fed mid-hill conditions of Himachal Pradesh (HP). The soil was collected from a declining apple orchard in village Habban (HP). The soil in a heap was sterilized with formalin (1:9) solution and immediately covered with polythene sheet. After three weeks, the soil heap was opened and worked in such a way to exclude formaldehyde fumes completely from the soil. The farm yard manure was mixed with soil and 50 L plastic containers were filled with the soil along with the plantation of polybag-raised apple seedling and clonal rootstocks. The treatments comprised of four rootstocks i.e. 'Merton 793', 'MM.l11', 'M.7' and seedling (origin: *Malus baccata*) grafted on 'Super Chief' and five soil agro-technique *viz*., soil fumigation with formaldehyde, plant growth-promoting rhizobacteria (*Bacillus licheniformis* CK-1) [PGPR], biocontrol (*Trichoderma viride*) and combined treatment (soil fumigation + PGPR + biocontrol) including untreated control. PGPR (250 mL with inoculum load of 10^8 CFU mL^{-1}) and biocontrol (10 g with inoculum load of 10^9 CFU g^{-1}) were applied at the time of planting in pits and then treatment repeated after every three months up to December 2016. The experiment was conducted in two factorial completely randomized design with each treatment replicated three times. The observations regarding growth traits *viz*., plant height, feathers, leaf area and plant volume were recorded in the month of October during both the year of study, as per the standard procedures suggested by Westwood (1978). The chlorophyll content was estimated as per Hiscox and Israelstam (1979) while the rate of photosynthesis, transpiration rate, stomatal conductance, variable fluorescence, photochemical efficiency, initial fluorescence efficiency, fluorescence, water use efficiency (WUE) and minimum stomatal resistance were estimated during the month of June 2015 and 2016 at 9:00 am to 12:00 noon using LICOR-6200 portable photosynthesis system and chlorophyll fluorescence meter (OS-30P). WUE was computed from the following relationship between the rate photosynthesis and the rate of transpiration with the help of LICOR- 6200 portable photosynthesis system.

$$\text{Water use efficiency} = \frac{\text{Rate of photosynthesis}}{\text{Rate of transpiration}}$$

The data was analyzed by two-way factorial ANOVA to assess the significant differences in treatments, if any, using SPSS computer package (SPSS-20 Inc. USA).

RESULTS AND DISCUSSION

The data presented in Tables 1 to 10 reveals the impact of different rootstocks and soil agro-techniques on various physiological traits of replanted apple plants. Apple 'Super Chief' grafted onto 'Merton 793' rootstock had significantly highest chlorophyll content (2.95 mg g^{-1}), rate of photosynthesis (9.68

Table 1: Effect of different rootstocks and soil treatments on chlorophyll content (mg g^{-1}) of apple plants at replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	M793	MM111	M7	Mean	Seedling	M793	MM111	M7	Mean
Control	2.56	2.81	2.75	2.65	2.70	2.58	2.80	2.75	2.66	2.70
Soil fumigation	2.66	2.89	2.79	2.73	2.77	2.70	2.90	2.84	2.76	2.80
PGPR	2.70	3.01	2.84	2.71	2.82	2.72	3.02	2.89	2.76	2.85
Biocontrol	2.77	3.00	2.89	2.78	2.86	2.81	3.02	2.95	2.81	2.90
Combined	2.86	3.02	2.91	2.87	2.92	2.89	3.07	2.97	2.93	2.97
Mean	2.71	2.95	2.84	2.75	2.81	2.74	2.97	2.88	2.78	2.84
SEM±	RS = 0.08; T = 0.09, RS x T = 0.19					RS = 0.01; T = 0.01, RS x T = 0.03				
$CD_{0.05}$	RS = 0.17; T = ns, RS x T = ns					RS = 0.02; T = 0.03, RS x T = 0.06				

µ mol m^{-2} sec^{-1}), transpiration rate (27.59 m mol m^{-2} sec^{-1}), stomatal conductance (0.778 m mol sec^{-1}), water use efficiency (0.351 µm mol^{-1}), variable fluorescence (137.53 Fv), photochemical efficiency (0.756 Fv Fm^{-1}), initial fluorescence efficiency (147.23 Fo), fluorescence (522.83 Fm) and minimum stomatal resistance (0.347 s cm^{-1}) during 2015. During the 2016 chlorophyll content (2.97 mg g^{-1}), rate of photosynthesis (10.25 µmol m^{-2} sec^{-1}), transpiration rate (28.03 m mol m^{-2} sec^{-1}), stomatal conductance (0.835 m mol sec^{-1}), water use efficiency (0.373 µm mol^{-1}), variable fluorescence (142.63 Fv), photochemical efficiency (0.774 Fv Fm^{-1}), initial fluorescence efficiency (160.10 Fo), fluorescence (536.43 Fm) and minimum stomatal resistance (0.491 s cm^{-1}). The values with respect to above parameters were minimum in treatment 'seedling rootstock'. Among all the treatments, the maximum chlorophyll content (2.92 mg g^{-1}), rate of photosynthesis (10.44 µ mol m^{-2} s^{-1}), transpiration

Table 2: Effect of different rootstocks and treatments on the rate of photosynthesis (µ mol m^{-2} sec^{-1}) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	7.68	9.16	8.99	8.46	8.57	8.82	9.43	9.69	9.48	9.35
Soil fumigation	7.81	8.53	8.38	8.31	8.26	9.31	10.03	9.80	9.61	9.69
PGPR	9.65	10.07	9.96	9.85	9.88	9.95	10.83	10.47	10.41	10.41
Biocontrol	9.43	9.85	9.74	9.63	9.66	9.33	10.15	10.24	9.53	9.81
Combined	10.15	10.79	10.48	10.33	10.44	10.48	10.82	10.68	10.58	10.64
Mean	8.94	9.68	9.51	9.31	9.36	9.58	10.25	10.17	9.92	9.98
SEM±	RS = 0.01; T = 0.02; R × T = 0.03					RS = 0.01; T = 0.01; R × T = 0.03				
$CD_{0.05}$	RS = 0.03; T = 0.03; R × T = 0.06					RS = 0.02; T = 0.03; R × T = 0.05				

Table 3: Effect of different rootstocks and treatments on transpiration rate (m mol m^{-2} s^{-1}) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	24.01	25.72	25.45	25.03	25.05	24.84	27.02	26.49	25.58	25.98
Soil fumigation	25.72	26.32	25.64	25.54	25.81	26.44	27.02	26.70	25.47	26.41
PGPR	27.70	28.10	27.92	27.79	27.88	27.84	28.24	28.12	28.04	28.06
Biocontrol	27.68	28.08	27.90	27.77	27.86	27.74	28.14	28.02	27.94	27.96
Combined	29.16	29.71	29.55	29.19	29.40	29.05	29.74	29.35	29.24	29.34
Mean	26.85	27.59	27.29	27.06	27.20	27.18	28.03	27.73	27.25	27.55
SEM±	RS = 0.05; T = 0.05; R × T = 0.11					RS = 0.03; T = 0.03; R × T = 0.07				
$CD_{0.05}$	RS = 0.10; T = 0.11; R × T = 0.21					RS = 0.06; T = 0.07; R × T = 0.14				

Table 4: Effect of different rootstocks and treatments on stomata conductance (m mol/s) of apple plants in replanted site

Treatment (T) \ Rootstocks (RS)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	0.580	0.733	0.651	0.609	0.643	0.715	0.811	0.769	0.758	0.763
Soil fumigation	0.681	0.699	0.640	0.634	0.664	0.704	0.786	0.730	0.700	0.730
PGPR	0.780	0.806	0.729	0.754	0.767	0.788	0.876	0.787	0.730	0.795
Biocontrol	0.810	0.821	0.745	0.954	0.833	0.766	0.808	0.754	0.722	0.762
Combined	0.817	0.833	0.870	0.766	0.822	0.811	0.895	0.838	0.807	0.838
Mean	0.734	0.778	0.727	0.744	0.746	0.756	0.835	0.776	0.743	0.778
SEM±	RS = 0.19; T = 0.22; R × T = 0.43					RS = 0.09; T = 0.10; R × T = 0.19				
$CD_{0.05}$	RS = ns; T = 0.44; R × T = 0.88					RS = 0.17; T = 0.19; R × T = 0.38				

rate (29.40 m mol m^{-2} s^{-1}), stomatal conductance (0.822 m mol s^{-1}), water use efficiency (0.355 µm mol^{-1}), variable fluorescence (164.29 Fv), photochemical efficiency (0.762 Fv/Fm), initial fluorescence efficiency (163.43 Fo), fluorescence (563.83 Fm) and minimum stomatal resistance (0.440 s cm^{-1}) during 2015. The highest chlorophyll content (2.97 mg g^{-1}), rate of photosynthesis (10.64 µ mol m^{-2} s^{-1}), transpiration rate (29.34 m mol m^{-2} s^{-1}), stomatal conductance (0.838 m mol s^{-1}), variable fluorescence (175.32 Fv), photochemical efficiency (0.778 Fv/Fm), initial fluorescence efficiency (173.00 Fo), fluorescence (581.92 Fm) and minimum stomatal resistance (0.466 s cm^{-1}) were recorded highest in combined soil agro-technique as well as highest water use efficiency (0.375 µm mol^{-1}) in soil fumigation treatment in 2016. However, the lowest chlorophyll content, rate of photosynthesis, transpiration rate, stomatal conductance, water use efficiency, variable fluorescence, photochemical efficiency, initial fluorescence efficiency, fluorescence and maximum stomatal resistance were recorded in control (untreated soil) [Tables 1 - 10].

The interaction effect of rootstock and soil agro-technique combinations revealed that 'Merton 793' rootstock × combined treatment recorded highest chlorophyll content (3.02 mg g^{-1}), rate of photosynthesis (10.79 µmol m^{-2} sec^{-1}), transpiration rate (29.71 m mol m^{-2} sec^{-1}), WUE (0.363 µm mol^{-1}), variable fluorescence (68.00 Fv) photochemical efficiency (0.779 Fv/Fm), initial fluorescence efficiency (167.43 Fo), fluorescence (571.83 Fm), and minimum stomatal resistance (0.326 s cm^{-1}). The highest stomatal conductance (0.954 m mol sec^{-1}) was recorded in treatment 'biocontrol × M.7' during 2015. The maximum chlorophyll content (3.07 mg g^{-1}), rate of photosynthesis (10.82 µmol m^{-2} sec^{-1}), transpiration rate (29.74 m mol m^{-2} sec^{-1}), stomatal conductance (0.895 m mol sec^{-1}), variable fluorescence (179.23 Fv), photochemical efficiency (0.805 Fv/Fm), initial fluorescence efficiency (177.50 Fo) and fluorescence (587.83 Fm); and minimum stomatal resistance (0.447 s cm^{-1}) were recorded in "combined soil agro-techniques × 'Merton 793' treatment as compared to other rootstocks and individual soil agro-techniques. The highest water use efficiency (0.385 µm mol^{-1}) was recorded in treatment 'PGPR × Merton 793' and lowest in 'seedling × control' combinations during 2016.

Table 5: Effect of different rootstocks and agro-techniques on stomata resistance (s cm^{-1}) of apple plants at replanted site

Treatment (T) \ Rootstocks (RS)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	0.511	0.388	0.502	0.476	0.469	0.618	0.583	0.648	0.568	0.604
Soil fumigation	0.471	0.321	0.443	0.432	0.417	0.511	0.438	0.454	0.480	0.471
PGPR	0.467	0.334	0.453	0.417	0.418	0.508	0.453	0.447	0.471	0.470
Biocontrol	0.497	0.368	0.481	0.471	0.454	0.547	0.532	0.512	0.663	0.564
Combined	0.458	0.326	0.446	0.425	0.414	0.498	0.447	0.452	0.465	0.466
Mean	0.481	0.347	0.465	0.444	0.434	0.537	0.491	0.503	0.530	0.515
SEM±	RS = 0.2; T = 0.3; R × T = 0.60					RS = 0.12; T = 0.14; R × T = 0.28				
$CD_{0.05}$	RS = 0.5; T = 0.6; R × T = 0.11					RS = 0.25; T = 0.28; R × T = 0.56				

Table 6: Effect of different rootstocks and agro-techniques on water use efficiency (µm mol^{-1}) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	0.320	0.356	0.353	0.338	0.342	0.367	0.367	0.381	0.379	0.373
Soil fumigation	0.304	0.324	0.327	0.325	0.320	0.362	0.381	0.382	0.376	0.375
PGPR	0.348	0.358	0.357	0.354	0.354	0.359	0.385	0.375	0.374	0.373
Biocontrol	0.341	0.351	0.349	0.347	0.347	0.337	0.361	0.367	0.343	0.352
Combined	0.348	0.363	0.355	0.354	0.355	0.359	0.364	0.361	0.362	0.362
Mean	0.332	0.351	0.348	0.344	0.344	0.357	0.372	0.373	0.367	0.367
SEM±	RS = 0.1; T = 0.1; R × T = 0.2					RS = 0.1; T = 0.1; R × T = 0.2				
$CD_{0.05}$	RS = 0.2; T = 0.2; R × T = 0.4					RS = 0.1; T = 0.2; R × T = 0.4				

The interaction between rootstocks and treatments was found to be non-significant in respect of stomatal conductance. Numerically, all other rootstocks registered higher stomatal conductance with combined treatment combination during 2016. However, lowest chlorophyll content, rate of photosynthesis, transpiration rate, stomatal conductance, water use efficiency, variable fluorescence, photochemical efficiency, initial fluorescence efficiency, fluorescence and maximum stomatal resistance in seedling × control combination during both the year of study.

Seedling rootstock was found more sensitive to replant problem because of its susceptibility to soil-borne disease. In general, replant sites have more pathogens, thereby, directly affect the plant growth and development of new saplings. The clonal rootstocks (‘M.793’, ‘MM.111’ and ‘M.7’) have

Table 7: Effect of different rootstocks and treatments on variable fluorescence (Fv) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	114.17	118.17	115.00	114.00	115.33	117.23	122.23	117.90	115.90	118.32
Soil fumigation	118.17	125.17	123.00	122.00	122.08	120.23	127.23	125.90	122.90	124.07
PGPR	134.17	139.17	136.00	135.00	136.08	143.23	145.23	143.90	142.90	143.82
Biocontrol	130.17	137.17	132.00	130.00	132.33	132.23	139.23	133.90	132.90	134.57
Combined	162.17	168.00	164.00	163.00	164.29	172.23	179.23	175.90	173.90	175.32
Mean	131.77	137.53	134.00	132.80	134.03	137.03	142.63	139.50	137.70	139.22
SEM±	RS = 0.37; T = 0.41; R × T = 0.82					RS = 0.42; T = 0.47; R × T = 0.95				
$CD_{0.05}$	RS = 0.74; T = 0.83; R × T = 1.66					RS = 0.46; T = 0.96; R × T = 1.91				

Table 8: Effect of different rootstocks and treatments on photochemical efficiency (Fv/Fm) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	0.726	0.739	0.729	0.716	0.728	0.732	0.762	0.744	0.731	0.742
Soil fumigation	0.728	0.742	0.737	0.726	0.733	0.735	0.758	0.748	0.737	0.745
PGPR	0.740	0.759	0.746	0.735	0.745	0.745	0.768	0.755	0.743	0.753
Biocontrol	0.741	0.758	0.744	0.731	0.744	0.748	0.779	0.764	0.750	0.760
Combined	0.749	0.779	0.769	0.751	0.762	0.757	0.805	0.782	0.769	0.778
Mean	0.737	0.756	0.745	0.732	0.742	0.744	0.774	0.759	0.746	0.756
SEM±	RS = 0.3; T = 0.3; R × T = 0.6					RS = 0.5; T = 0.6; R × T = 0.11				
$CD_{0.05}$	RS = 0.5; T = 0.6; R × T = 0.12					RS = 0.10; T = 0.11; R × T = 0.23				

Table 9: Effect of different rootstocks and treatments on initial fluorescence efficiency (Fo) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	134.50	134.43	133.43	132.43	133.70	136.50	140.50	136.50	134.50	137.00
Soil fumigation	137.50	138.43	135.43	134.43	136.45	143.50	147.50	144.50	143.50	144.75
PGPR	142.50	148.43	147.43	146.43	146.20	158.50	169.50	165.50	162.50	164.00
Biocontrol	146.50	147.43	146.43	145.43	146.45	155.50	165.50	162.50	159.50	160.75
Combined	158.43	167.43	164.43	163.43	163.43	171.50	177.50	172.50	170.50	173.00
Mean	143.89	147.23	145.43	144.43	145.25	153.10	160.10	156.30	154.10	155.90
SEM±	RS = 0.75; T = 0.84; R × T = 1.67					RS = 0.63; T = 0.71; R × T = 1.41				
$CD_{0.05}$	RS = 1.51; T = 1.69; R × T = 3.39					RS = 1.28; T = 1.43; R × T = 2.86				

previously been reported to be more tolerant to soil-borne diseases (Kviklys *et al.*, 2007; Singh *et al.*, 2017) and have more biomass of adventitious roots. Production of plant growth hormones like auxin, gibberellins and cytokinin by plant growth-promoting rhizobacteria have been suggested as possible mechanisms of action influencing the plant growth. The findings are in line with Seo Shahin *et al.* (2010) who also recorded increased plant height and spread with the use of plant growth-promoting rhizobacteria and *Trichoderma viride*. The chlorophyll fluorescence analysis technique was based on photosynthesis and seems ideal probe to study photosynthetic physiology and detect the relationship between plant and adversity stress (Sayed, 2003). The fixed fluorescence (Fo) was the yield of PS-I reaction centre fully opened, which relate to chlorophyll concentration. The maximum fluorescence

Table 10: Effect of different rootstocks and treatments on fluorescence (Fm) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	453.83	485.83	471.50	470.50	470.42	468.83	498.83	490.50	478.50	484.17
Soil fumigation	459.83	481.83	464.50	456.50	465.67	575.83	494.83	486.50	476.50	508.42
PGPR	531.83	538.83	528.50	529.17	532.08	536.83	554.83	552.50	544.50	547.17
Biocontrol	525.83	535.83	522.50	510.17	523.58	534.83	545.83	545.50	533.50	539.92
Combined	563.83	571.83	560.50	559.17	563.83	577.83	587.83	585.50	576.50	581.92
Mean	507.03	522.83	509.50	505.10	511.12	538.83	536.43	532.10	521.90	532.32
SEM±	RS = 2.53; T = 2.83; R × T = 5.65					RS = 5.28; T = 5.90; R × T = 11.81				
$CD_{0.05}$	RS = 5.11; T = 5.71; R × T = 11.42					RS = 10.67; T = 11.93; R × T = 23.87				

Table 11: Effect of different rootstocks and treatments on plant height (cm) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	130.33	142.68	131.53	132.30	134.21	149.11	165.44	150.78	146.00	152.83
Soil fumigation	140.47	155.57	145.06	140.96	145.52	163.14	176.48	161.22	154.32	163.79
PGPR	160.27	165.23	162.31	158.29	161.53	182.44	186.57	178.32	173.29	180.15
Biocontrol	153.35	163.57	158.96	155.30	157.80	171.35	185.66	173.44	169.33	174.94
Combined	173.17	201.32	183.90	178.24	184.16	204.71	251.68	224.22	211.91	223.13
Mean	151.52	165.67	156.35	153.02	156.64	174.15	193.17	177.59	170.97	178.97
SEM±	RS = 1.35; T = 1.50; R × T = 3.01					RS = 2.23; T = 2.49; R × T = 4.99				
$CD_{0.05}$	RS = 2.72; T = 3.04; R × T = 6.08					RS = 4.51; T = 5.04; R × T = 10.08				

Table 12: Effect of different rootstocks and treatments on leaf area (cm^2) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	34.31	35.75	33.25	33.88	34.30	34.32	36.50	33.41	33.98	34.55
Soil fumigation	34.19	35.36	33.76	33.90	34.30	34.71	35.84	34.37	33.81	34.68
PGPR	37.22	39.75	37.99	38.01	38.24	40.04	40.76	39.37	38.95	39.78
Biocontrol	37.21	39.40	37.89	37.97	38.12	38.83	40.32	39.29	38.67	39.28
Combined	43.20	48.32	47.08	45.89	46.12	44.09	48.70	47.16	46.97	46.73
Mean	37.22	39.71	38.00	37.93	38.22	38.40	40.42	38.72	38.48	39.00
SEM±	RS = 0.35; T = 0.37; R × T = 0.79					RS = 0.31; T = 0.35; R × T = 0.70				
$CD_{0.05}$	RS = 0.71; T = 0.81; R × T = 1.59					RS = 0.63; T = 0.71; R × T = 1.41				

(Fm) was the yield of PS-II reaction centre fully closed, which reflect the electron transfer situation of PS-II (Schreiber *et al.,* 1994).

Plant photosynthetic organ is very sensitive to adversity stress, and may often be the primary position of suffers (Xiuwuguo *et al.*, 2015). As an important parameter of chlorophyll fluorescence, Fv/Fm was well used as a sensitive indicator of plant photosynthetic performance (Baker, 2008). It was the maximum quantum efficiency of PS-II photochemistry, reflecting the largest solar energy conversion efficiency in PS-II reaction centre. Fv/Fm normally remained at a relatively constant level under unstressed conditions; however, decreased to varying degrees under stress conditions (Baker, 2008). In this study, replant condition could increase Fo and decrease Fm in replant-susceptible resources, which indicated that the maximal photochemical efficiency decreased and photo-inhibition intensified in seedling. At the same time, the relative chlorophyll content in replanting soil was lower than control treatment and led to decrease in photosynthesis which influenced dry matter synthesis and transport and ultimately to a dramatic decline in plant growth. For combined treatment with high replant resistance, the increase of net photosynthesis rate might have caused in the increase of relative chlorophyll content and the enhancement of maximal photochemical efficiency of PS-II. For Merton 793 rootstock, relative chlorophyll content dropped, but the PS-II maximum photochemical efficiency enhanced, leading photosynthetic rate not influenced by replanting (Singh *et al.*, 2018).

In present study, different rootstocks and soil agro-techniques significantly increased plant growth parameters. Among the rootstocks, 'Merton 793' rootstock had significantly highest plant height (165.67 cm), number of feathers (3.51), leaf area (39.71 cm^2) and plant volume (1.40 m^3) during 2015. In 2016, the maximum plant height (193.17 cm), number of feathers (6.79), leaf area (40.42 cm^2) and plant volume (1.64 m^3) was recorded in 'Merton 793' rootstock. However, the lowest plant height, number of feathers, leaf area and plant volume were recorded in seedling rootstock.

Table 13: Effect of different rootstocks and treatments on number of feathers of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	2.18	2.68	2.06	1.86	2.20	3.33	5.23	4.10	3.36	4.01
Soil fumigation	2.18	3.18	2.36	1.86	2.40	3.73	6.93	4.46	3.96	4.77
PGPR	2.73	3.55	2.93	2.78	3.00	5.53	7.72	6.37	6.47	6.52
Biocontrol	2.68	3.38	2.86	2.66	2.90	5.33	6.93	6.26	6.36	6.22
Combined	2.78	4.78	3.26	2.96	3.45	6.73	8.03	6.96	6.76	7.12
Mean	2.51	3.51	2.70	2.43	2.79	4.93	6.97	5.63	5.39	5.73
SEM±	RS = 0.12; T = 0.14; R × T = 0.28					RS = 0.25; T = 0.28; R × T = 0.56				
$CD_{0.05}$	RS = 0.25; T = 0.28; R × T = ns					RS = 0.50; T = 0.56; R × T = ns				

Table 14: Effect of different rootstocks and treatments on plant volume (m^3) of apple plants in replanted site

Rootstocks (RS) / Treatment (T)	2015					2016				
	Seedling	Merton 793	MM.111	M.7	Mean	Seedling	Merton 793	MM.111	M.7	Mean
Control	0.61	0.97	0.73	0.69	0.75	0.69	1.13	0.84	0.77	0.86
Soil fumigation	0.84	1.17	0.90	0.87	0.94	0.97	1.33	1.00	0.95	1.06
PGPR	1.18	1.38	1.34	1.15	1.26	1.35	1.56	1.47	1.26	1.41
Biocontrol	1.06	1.25	1.09	1.06	1.12	1.19	1.42	1.19	1.16	1.24
Combined	1.72	2.22	1.80	1.75	1.87	2.03	2.78	2.20	2.08	2.27
Mean	1.08	1.40	1.17	1.11	1.19	1.25	1.64	1.34	1.24	1.37
SEM±	RS = 0.3; T = 0.3; R × T = 0.7					RS = 0.4; T = 0.5; R × T = 0.9				
$CD_{0.05}$	RS = 0.6; T = 0.7; R × T = 1.4					RS = 0.8; T = 0.9; R × T = 1.9				

Among the soil agro-techniques, the highest plant height (184.16 cm), number of feathers (3.45), leaf area (46.12 cm^2) and plant volume (1.87 m^3) during 2015 were in combined soil treatment. Similarly, in 2016 the maximum plant height (223.13 cm), number of feathers (7.12), leaf area (46.73 cm^2) and plant volume (2.27 m^3) were recorded in combined treatment. The minimum plant height, number of feathers, leaf area and plant volume were found in control (Tables 11-14). Among the rootstocks and soil agro-technique combinations, the highest plant height (201.32 cm), number of feathers (4.78), leaf area (48.32 cm^2) and plant volume (2.22 m^3) during 2015 was in combined soil agro-techniques. Similarly, in 2016 the highest plant height (251.68 cm), number of feathers (8.03), leaf area (48.70 cm^2) and plant volume (2.78 m^3) were noticed in combined soil agro-technique in Merton 793 rootstock. However, the lowest plant height, leaf area, number of feather and plant volume were found in untreated control × seedling combinations (Tables 11-14).

From the present study, it may be concluded that ‘Merton 793’ is most suited apple rootstock for replantation. Further, it is also inferred that combined treatment (soil fumigation + PGPR + biocontrol) is an appropriate soil agro-technique to mitigate replantation problem in apple. The consortium of ‘M.793’ rootstock and combined treatment recorded a significant increase in plant growth and physiological parameters in the apple under the replanted site. Most of the growth and physiological traits had a positive correlation with plant volume in the present study.

The increase in leaf chlorophyll might be a result of increased leaf area, the balanced nutritional environment in the soil that kept iron physiologically active for chlorophyll synthesis in certain plants (Singh and Sharma 2017). Plants raised on ‘MM.106’ rootstocks also had significantly greater leaf chlorophyll content and rate of photosynthesis than those on *M. baccata* Shillong and seedling rootstocks which registered least chlorophyll content and rate of photosynthesis (Leinfelder and Merwin, 2006; Singh *et al.*, 2019). From the present study, it may be concluded that ‘Merton 793’ is the most suitable apple rootstock for replantation. It is also inferred that combined treatment (soil fumigation + PGPR + biocontrol) is an appropriate soil agro-technique to mitigate replantation problem in apple. The consortium of ‘M.793’ rootstock and combined treatment recorded significant increase in plant growth and physiological parameters in apple under replanted site. Most growth and physiological traits showed positive correlation with plant volume.

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