Effect of soil solarization on true potato (*Solanum tuberosum* L.) seed germination, seedling growth, weed population and tuber yield

RAJ KUMAR and JYOTSANA SHARMA

Central Potato Research Station, Post Bag No. 1, Model Town P.O., Jalandhar-144003, India

Accepted for publication: 19 February 2005

Additional keywords: Cyperus rotundus, Cornopus didymus, cost-effective

Summary

True potato seed of 17 progenies were evaluated during 2002–03 and 2003–04 crop seasons for 12 characters related to seed germination, seedling growth and weed population in nursery beds and tuber yield of transplanted seedlings under non-solarized field conditions. Solarization was found to have beneficial effect on seed germination, seedling growth and yield of transplanted seedlings. Total weeds and major annual weed *Cornopus didymus* were reduced to a great extent due to solarization. However solarization had no effect on *Cyperus rotundus*. Progenies also showed significant differences among themselves for the various characters studied. The progeny × solarization interaction was also significant for all the characters. Yield increase in present study shows that the approach involving raising of seedlings in solarized nursery beds and subsequent transfer of seedlings to non-solarized field would be cost-effective and profitable for raising true seed crop of potato.

Introduction

Soil solarization refers to covering the soil with transparent sheets, usually transparent polyethylene, during hot summer months for capturing solar energy to heat the soil in the open field or glasshouse. Solarization is a hydrothermal process, which brings about thermal and other physical, chemical and biological changes in the moist soil during, and even after mulching (Stapleton & DeVay, 1986). Soil solarization is a simple nonchemical method, which frequently enhances beneficial processes in the soil. Soil solarization is restricted to certain climatic areas and seasons. Beneficial effects of soil solarization include eradication or reduction of soil pathogen population, weed control, increased growth response and yield, and improvement of quality of produce (Katan & DeVay, 1991). Potato crop is plagued by numerous soil-borne pathogens that include fungi, bacteria and nematodes. Since soil-borne diseases of potato may produce heavy losses at all stages of growth, this crop is an excellent candidate for investigating the effect of solarization (Davis & Sorensen, 1986). Soil solarization has previously been found effective against various potato diseases and pests (Elad et al., 1980; Katan, 1981; Davis & Sorensen, 1986; Davis, 1991; Denner et al., 2000; Triki et al., 2001). Soil solarization being a climate-dependent method, has some limitations and its adaptation to any new region requires thorough research.

In traditional potato improvement programmes, the F_1 generation is raised from true potato seed (TPS). Commercial potato crop is also raised from botanical seeds in some areas. The enhancement of true seed germination would be beneficial to several areas of potato research and culture. Faster germination of TPS would promote uniform seedlings, resulting in more uniform transplants. A technique which makes transplants more uniform might also help to avoid inadvertent selection for short dormancy (Simmonds, 1964) since large seedlings from the first germinated seeds are often the ones chosen for transplanting. Due to the heterozygous and tetraploid nature of cultivated potato, very large numbers of seedlings are raised to have a fair chance of getting a desirable recombinant in a breeding programme. Better germination of seeds would allow a large number of seedlings from a cross to be evaluated for their performance. Enhanced germination and better seedling growth would be beneficial when the commercial potato crop is raised from TPS. Considering this, the aim of the study was to know the effect of the soil solarization under sub-tropical plains on various characters related to germination of TPS, seedling growth and yield.

Materials and methods

Materials. True potato seeds of 17 cross/self progenies were sown in nursery beds. The progenies studied were: JF 4841 × CP 2135, CP 3125 × J.93-68, JN 1197 × J.93-68, J.93-68 × CP 3125, CP 2013 × CP 2013, JN 1197 × JX 214, JN 1197 × MS/82-797, JN 1197 × JN 1197, MS/92-3128 × MS/92-3128, CP 1909 × CP 1909, CP 3290 × JEX/A 827, CP 3290 × CP 3290, Kufri Chipsona-1 × J.92-148, Kufri Chipsona-1 × J.92-111, Kufri Chipsona-1 × MS/82-717, CP 1358 × CP 1358 and Kufri Chipsona-1 × MS/82-797.

Raising of seedlings. Raising of seedlings was done at Central Potato Research Station Jalandhar (31° 02' N, 75° 02' E, 237 m amsl). Nursery beds of 1.25-meter length and 1.25-meter breadth were made and raised to about 10 cm from the field level. The border of each nursery bed was made using bricks to prepare the wall of the seedbed. Substrate for the nursery bed was prepared by mixing sterilized soil and well rotten FYM (farm yard manure) in a 1:1 ratio. The 10-cm depth of the nursery bed was filled with substrate. Nursery beds were irrigated with watering can. Soil solarization was achieved by hydrothermal soil heating by covering moist soil with transparent polythene sheets of 75 μm thickness prior to sowing during the hot summer months of May and June 2002 and 2003. Soil temperatures were recorded daily at 2.30 p.m. at 10 cm depth in three replicates each of solarized and non-solarized beds by using soil-thermometer. Two strips each containing 7 nursery beds were soil solarized while similar two strips on the southern side of solarized strips were kept non-solarized. Central 1 m length and 1 m breadth of each nursery bed were used for TPS sowing to eliminate border effects by leaving 25 cm area all around the bed. Each bed of one square meter was divided into four plots for sowing of 500 seeds of a progeny in each plot. Sowing of the seeds in nursery beds was done in a randomised complete block design with split plot. Solarization was main-plot treatment with cross/self progenies as sub-plot treatments. True potato seeds (TPS) were treated with 2000 ppm gibberrelic acid before sowing to break the dormancy of the seeds. TPS were sown in nursery beds in the last week of September 2002 and 2003. TPS were sown in furrows of 0.5 cm depth and 5 cm apart. The beds were then watered with a sprayer to keep the soil moist. Beds were irrigated thrice a day for about a week after TPS sowing. Subsequently water was sprayed twice a day. Nursery beds were protected from direct sunlight by providing shade using hessian cloth cover from 10 am to 4 pm for fifteen days after sowing. Seedlings were transplanted to field in about 30 days of TPS sowing when seedlings were having 4–5 leaves. Observations were recorded on seed germination at 8, 11,15 days after sowing; nutgrass (*Cyperus rotundus*), *Cornopus didimus* and total weed population at 9 and 13 days after sowing; and fresh weight of 10 seedlings at 15 days after sowing. The rate of germination was measured in terms of coefficient of velocity as per the formula devised by Kotowski (1926), using the equation:

$$\text{Coefficient of velocity} = 100(A_1 + A_2 ---- A_x) / (A_1T_1 + A_2T_2 ---- A_xT_x)$$

A = the number of seeds germinated, T = the number of days after sowing, corresponding to A.

Seedlings transplanting in field. For transplanting of seedlings, the field was prepared by following the traditional practices used to grow a potato crop from tuber seed. Rooted seedlings were carefully removed from nursery beds, taken to field and transplanted by placing them in openings made by a hand hoe and lightly pressed. Seedlings were transplanted in the later part of the day to avoid mortality due to heat shock. Immediately after transplanting, water was applied to furrows to half the height of the ridge. Seedlings of 17 progenies were transplanted in the field in randomized complete block design with three replications and plot size consisting of 4 rows of 20 seedlings each. Seedling to seedling and inter-row distances were 20 cm and 60 cm, respectively. Haulm cutting was done 75 days after transplanting. Harvesting was done 20 days after haulm cutting. At the time of harvest data on per plot yield were recorded.

Statistical analysis. The data were pooled over years and analysis of variance was done according to randomized complete block design with split plot (Gomez & Gomez, 1984). The data on germination count, nutgrass, *Cornopus* and total weed count were transformed before analysis by square-root transformation.

Results and discussion

Effect of solarization on soil temperature. The soil temperatures during both the years at 10 cm depth were higher in solarized soils. During 2002–2003, the mean maximum temperatures were 48.5 and 39.6 °C for solarized and non-solarized soils, respectively. Similarly during 2003–2004 season, the mean maximum temperatures in solarized and non-solarized soils were 49.0 and 40.0 °C, respectively. Heating of the soil is the key factor in solarization, which brings about beneficial changes in the soil (Katan & De Vay, 1991).

Analysis of variance. Error variances were homogeneous over years for all the 12 characters. Hence, results are presented based on pooled analysis of data over two years (crop seasons). Analysis of variance in split-plot design for various characters with soil solarization as main-plot treatment and progenies as sub-plot treatment are presented in Table 1. Year had a significant effect on germination at 8 days, coefficient of velocity and nutgrass population at 9 and 13 days after sowing. The main-plot treatment solarization was significant for all characters except nutgrass population at 9 and 13 days. Year × solarization interaction was significant for fresh weight of seedlings, germination at 8 and 11 days after sowing, coefficient of velocity and nutgrass population at 9 and 13 days after sowing. The results show that effect of solarization varied with environment/season for these characters. The 17 cross progenies showed highly significant differences among themselves for all the 12 characters studied. For all characters interaction of crosses with year, solarization and year × solarization were significant with the exception of year × solarization × cross interaction for yield in the field and germination at 15 days. Although the solarization × cross interaction was significant for all the characters, the effect of the solarization was significant on all the 17 progenies for the characters fresh weight of seedlings, germination at 11 and 15 days, *Cornopus* and total weed population at 9 and 13 days after sowing (data not given).

Germination and seedling growth. Germination was significantly higher with solarization treatment at each stage of 8, 11 and 15 days after sowing (Table 2). The germination at 15 days after sowing represented maximum germination. Per cent germination increase at earlier stages was more compared to germination increase at 15 days after sowing. Soil solarization has also earlier been reported to increase total and transplantable seedlings in tobacco (Patel et al., 1995). There was a significant increase in coefficient of velocity due to faster germination of seeds under solarization treatment. The coefficient of velocity recorded a 1.31% increase. There was a significant increase in fresh weight of seedlings with solarization treatment. Fresh weight of seedlings recorded 33.3% increase. Triki et al. (2001) reported improvement in plant growth of potato due to soil solarization. Enhanced germination and increased growth of seedlings in the present study may be due to improvement in chemical composition of the soil. Solarization of soils is reported to affect not only the biotic composition in the soil environment, but also the physical structure and chemical composition of the soil (Katan & DeVay, 1991), and hence crop fertilization and plant growth (Stapleton et al., 1985). Soil solarization increases concentration of soluble organic matter and minerals in soil, improves physical properties of soil, avoids salt accumulation in soil surface and improves leaching of soils (Al-Kayassi et al., 1989).

Table 1. Analysis of variance for 12 characters.

Source	Df	Mean square											
		G8	G11	G15	CV	FW10	N9	N13	C9	C13	TW9	TW13	Yd
Year	1	12.7**	1.52	0.05	0.110**	0.08	2.08**	3.16**	0.003	0.02	0.34	0.71	1.25
Replications in years	4	0.16	0.27	0.04	0.0001	0.02	0.06	0.04	0.34	0.25	0.38	0.27	0.37
Solarization	1	281**	156**	119**	0.595**	49.5**	0.15	0.10	444**	426**	347**	334**	404**
Year × solarization	1	32.3**	6.94*	0.17	0.318**	0.28*	1.21**	0.57**	0.11	1.36	0.02	1.03	10.6
Error	4	0.17	0.40	0.08	0.001	0.02	0.03	0.02	0.21	0.22	0.18	0.17	3.45
Progeny	16	303**	41.9**	8.16**	1.857**	18.7**	3.70**	4.03**	6.22**	5.39**	6.65**	5.44**	97.0**
Year × progeny	16	9.02**	3.74**	1.06**	0.077**	0.87**	0.25**	0.28**	1.06**	1.00**	0.93**	0.88**	6.77**
Solarization × progeny	16	3.63**	2.94**	1.80**	0.018**	0.67**	0.71**	0.65**	4.79**	5.21**	3.32**	3.42**	2.70**
Year × solarization × progeny	16	3.51**	1.86**	0.11	0.030**	0.08*	0.15**	0.17**	0.43**	0.41**	0.39**	0.38**	1.16
Error	128	0.32	0.22	0.14	0.002	0.04	0.05	0.04	0.11	0.09	0.10	0.08	1.09

*$P \leq 0.05$; **$P \leq 0.01$; Df = degree of freedom; G8 = germination after 8 days of sowing; G11 = germination after 11 days of sowing; G15 = germination after 15 days of sowing; CV = coefficient of germination velocity; FW10 = fresh weight (g) of 10 seedlings; N9 = nutgrass population after 9 days of sowing; N13 = nutgrass population after 13 days of sowing; C9 = *Cornopus* population after 9 days of sowing; C13 = *Cornopus* population after 13 days of sowing; TW9 = total weed population after 9 days of sowing; TW13 = total weed population after 13 days of sowing; Yd = yield (kg per plot).

Table 2. Effect of solarization on seedling germination, growth and weed populations.

Treatment	Character											
	G8	G11	G15	CV	FW10	N9	N13	C9	C13	TW9	TW 13	Yd
Solarized	275	399	455	8.37	3.94	4.57	5.09	10.2	12.3	14.8	17.4	18.3
	(16.0)	(19.9)	(21.3)	–	–	(2.00)	(2.13)	(3.10)	(3.41)	(3.78)	(4.11)	–
Control (non-solarized)	215	335	393	8.26	2.96	4.05	4.66	38.2	41.1	42.2	45.8	15.5
	(13.6)	(18.2)	(19.8)	–	–	(1.94)	(2.08)	(6.06)	(6.30)	(6.39)	(6.67)	–
Percent increase over control	27.8	19.1	15.7	1.31	33.3	13.0	9.3	–73.2	–70.2	–64.9	–62.1	18.2
$CD_{0.05}$	–	–	–	0.01	0.05	–	–	–	–	–	–	0.72
	(0.16)	(0.25)	(0.11)	–	–	(0.07)	(0.05)	(0.18)	(0.18)	(0.17)	(0.16)	–
$CD_{0.01}$	–	–	–	0.02	0.09	–	–	–	–	–	–	1.20
	(0.27)	(0.41)	(0.18)	–	–	(0.11)	(0.08)	(0.30)	(0.30)	(0.27)	(0.27)	–

Values in parentheses are based on square root values of original data. G8 = germination after 8 days of sowing; G11 = germination after 11 days of sowing; G15 = germination after 15 days of sowing; CV = coefficient of germination velocity; FW10 = fresh weight (g) of 10 seedlings; N9 = nutgrass population after 9 days of sowing; N13 = nutgrass population after 13 days of sowing; C9 = *Cornopus* population after 9 days of sowing; C13 = *Cornopus* population after 13 days of sowing; TW9 = total weed population after 9 days of sowing; TW13 = total weed population after 13 days of sowing; Yd = yield (kg per plot).

Weed control. There were no significant changes in nutgrass population at 9 and 13 days after sowing. This shows that solarization was not effective in controlling this perennial weed. However, nutgrass population was very low in nursery beds. The most predominant weed in nursery beds was *Cornopus didymus.* Solarization significantly decreased the *Cornopus* population both at 9 and 13 days after sowing. The populations of total weeds at 9 and 13 days after sowing were also significantly reduced. Although there was some increase in nutgrass population, it was non-significant. Slight increase in nutgrass population may also be due to decreased *Cornopus* population. *Cyperus rotundus* has been generally resistant to control by solarization (Katan et al., 1976; Stapleton & DeVay, 1986). Rubin & Benzamin (1984) and Egley (1983) reported enhanced germination of *C. rotundus* in solarized soils. Final *Cornopus* population was decreased by 70.2%, while final total weeds population was decreased by 62.1% due to solarization. Earlier studies reported the effectiveness of solarization against weeds especially annual weeds (Katan, 1981; Katan & DeVay, 1991; Trikima et al., 2001).

Yield of transplanted seedlings. In un-solarized field where seedlings were transplanted from nursery beds, yield of seedlings from solarized nursery bed was higher by 18.16% over seedlings transplanted from non-solarized nursery bed. The field crop was symptomless with no disease or pests and weeds were removed as and when they appeared. The yield increase in seedlings from solarized plot may be attributed to better health and vigour of seedlings transplanted in field. Soil solarization enhances plant growth even in the absence of known major pathogens (Katan, 1981; Gruenzweig et al., 1993). This phenomenon is known as increased growth response (IGR). Gruenzweig et al. (1993) reported distinct IGR in maize, cucumber, sorghum, tobacco and tomato plants in solarized soils under controlled conditions compared with control non-treated soil. Higher level of chlorophyll and protein contents were also reported in tomato leaves from solarized soil compared with those from the control. In addition delayed leaf senescence was also observed in plants from solarized soil. Increased growth response was also suggested within a potato clone A68113-4 that was highly resistant to *Verticillium dahliae* (Davis & Sorensen, 1986). Although this clone remained symptomless throughout the growing season, significant yield increase with this potato occurred (18%). Triki et al. (2001) reported improvement in potato yield due to soil solarization. Majority of solarization studies has been conducted in regions of high temperature. However, a positive effect of soil solarization on potato has been reported even under temperate climate (Davis & Sorensen, 1986). Davis & Sorensen (1986) reported very high yield increase upto 118% in potato clones susceptible to *Verticillium dahliae*. They also reported additional benefits such as suppression of common scab caused by *Streptomycin scabies*, a suppression of stem-lesions associated with both *Rhizoctonia solani* and *Colletotrichum atramentarium*, and an increase of specific gravity on a clone, increased yield and quality. Long term effects of solarization in disease control and yield increase extending for a second or even fourth crop had been observed (Stapleton & DeVay, 1986; Katan et al., 1983; Abdel-Rahim et al., 1988). Such long-term effects of solarization in control of *Verticillium* wilt of potato were also reported (Davis & Sorensen, 1986).

Use of soil solarization for potato production from tubers may be limited by cost (Elad et al., 1980). However the present approach involving solarization of nursery beds for sowing TPS and subsequent transplanting of seedlings to the un-solarized field would be beneficial and cost effective for raising potato crop from true (botanical) seeds. The area required in nursery beds is generally less than 1% of the area under transplanted seedling crop. This approach results in yield increase without involving much cost for tarping as the area to be solarized is comparatively very small for nursery beds.

Acknowledgements

The authors are highly thankful to Drs S.M. Paul Khurana, G.S. Kang and S.K. Pandey for providing facilities.

References

Abdel-Rahim, M.F., M.M. Satour, K.Y. Mickail, S.A. El-Eraki, A. Grinstein, Y. Chen & J. Katan, 1988. Effectiveness of soil solarization in furrow-irrigated Egyptian soils. *Plant Disease* 72: 143–146.

Al-Kayassi, A.W., S. Ahmed & R. Hussain, 1989. Influence of soil solarization on salt movements and distribution. *Plasticulture* 84: 47–53.

Davis, J.R., 1991. Soil solarization: yield and quality benefits for potato in a temperate climate- short- and long-term effects and integrated control. *FAO Plant Production and Protection Paper* 109: 28–36.

Davis, J.R. & L.H. Sorensen, 1986. Influence of soil solarization at moderate temperatures on potato genotypes with differing resistance to *Verticillium dahliae*. *Phytopathology* 70: 1021–1026.

Denner, F.D.N., C.P. Millard & F.C. Wehner, 2000. Effect of soil solarization and mouldboard ploughing on black dot of potato caused by *Colletotrichum coccodes*. *Potato Research* 43: 195–201.

Egley, G.H., 1983. Weed seed and seedling reduction by soil solarization with transparent polythene sheets. *Weed Science* 3: 404–408.

Elad, Y., J. Katan & I. Chet, 1980. Physical, biological and chemical control integrated for soil-borne diseases in Potatoes. *Phytopathology* 70: 418–422.

Gomez, K.A. & A.A. Gomez, 1984. Statistical procedures for agricultural research. John Wiley and Sons, New York, 680 pp.

Gruenzweig, J.M., H.D. Rabinowitch & J. Katan, 1993. Physiological and developmental aspects of increased plant growth in solarized soils. *Annals of Applied Biology* 122: 579–591.

Katan, J., 1981. Solar heating (solarization) of soil for control of soilborne pest. *Annual Review of Phytopathology* 17: 211–236.

Katan, J. & J.E. DeVay, 1991. Soil solarization. CRC Press Inc., Boca Raton, USA, 267 pp.

Katan, J., G. Fishler & A. Grinstein, 1983. Short- and long-term effects of soil solarization and crop sequences on *Fusarium* wilt and yield of cotton in Israel. *Phytopathology* 73: 1215–1219.

Katan, J., A. Greenberger, H. Alon & A. Grinstein, 1976. Solar heating by polyethylene mulching for the control of diseases caused by soil borne pathogens. *Phytopathology* 66: 683–688.

Kotowski, F., 1926. Temperature relations to germination of vegetable seed. *Proceedings of American Society of Horticulture* 23: 176–184.

Patel, H.R., M.G. Makwana & B.N. Patel, 1995. The control of nematode and weeds by soil solarization in Tobacco nursery: effects of the film thickness and of the covering duration. *Plasticulture* 107: 21–27.

Rubin, B. & A. Benjamin, 1984. Solar heating of the soil: involvement of environmental factors in the weed control process. *Weed Science* 32: 138–142.

Simmonds, N.W., 1964. The genetics of seed and tuber dormancy in the cultivated potatoes. *Heredity* 19: 489–504.

Stapleton, J.J. & J.E. DeVay, 1986. Soil solarization: a non-chemical approach for the management of plant pathogens and pests. *Crop Protection* 3: 190–198.

Stapleton, J.J. , J. Quick & J.E. DeVay, 1985. Soil solarization: effect on soil properties, crop fertilization and plant growth. *Soil Biology and Biochemistry* 17: 369–375.

Triki, M.A., S. Priou & M. El Mahjoub, 2001. Effect of soil solarization on soil-borne populations of *Phythium aphanidermatus* and *Fusarium solani* and on potato crop in Tunisia. *Potato Research* 44: 271–279.