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SOIL SOLARIZATION: A MANAGEMENT PRACTICE FOR MYCOTOXINS IN CORN

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Abstract

Strategies for the management of mycotoxins in corn using soil solarization alone and in combination with soil amendments (farm yard manure, chicken farm yard manure, neem leaves and biokhad) were developed at the National Agricultural Research Centre (NARC), Islamabad, Pakistan. Experiments with soil solarization showed a pronounced reduction in weed population soon after removal of the transparent polyethylene sheets. Solarization controlled weeds (98.5%), increased soil temperature by 11.5ºC over non-solarized soil at 10 cm depth, reduced soil-borne pests, reduced ear rot diseases (72.5%), conserved moisture, increased the availability of essential nutrients in the soil and hence enhanced the growth of corn plants. Soil solarization was found an effective method in controlling ear rots. In treated plots, grain yield was more than double due to pathogen control, enhanced available nutrients in the soil as well as no competition with weeds. Soil solarization applied with transparent polyethylene film was found the most effective in reducing the incidence of corn ear rots and consequently reduced mycotoxins (fumonisins and aflatoxins) in fields and stored corn. We can avoid the hazardous/ poisonous effects of different chemicals on plant and animal life and thus, soil solarization technology could be used for the management of mycotoxins in food grains in future.

Introduction

Mycotoxins are secondary metabolites produced by a variety of molds on several agricultural commodities under specific environmental conditions (Bean & Echandi, 1989). A broad spectrum of acute and chronic diseases in livestock is due to mycotoxins, which can remain as a residue in meat and milk, posing a possible threat to human health. The amount and type of mycotoxin varies with environmental conditions such as temperature and humidity. In temperate climates, the mycotoxins of major concern are the trichothecenes (including deoxynivalenol (DON), nivalenol (NIV), T-2 toxin and HT-2 toxin), zearalenone (ZEN), the fumonisins (FB) predominantly fumonisin B_1 (FB_1), the ochratoxins, predominantly ochratoxin A (OA) and vomitoxins. Whereas, aflatoxins (AF) are of major concern in food and feedstuffs imported from warmer tropical and subtropical regions. Of these, fumonisins and aflatoxins are the major mycotoxins in corn. These often occur in the field before harvest.

Fusarium is the most common ear rot disease in the Corn Belt; it can be found in nearly every maize field at harvest (Smith & White, 1988). The primary importance of *Fusarium* ear rot is its association with mycotoxins, particularly the fumonisins a class of mycotoxins produced mainly by the molds *Fusarium moniliforme (F. verticillioides), F. proliferatum* and several other *Fusarium* species that grow on agricultural commodities in the field or during storage. These mycotoxins have been found worldwide, primarily in corn. While, aflatoxins are naturally occurring toxin produced by the molds *Aspergillus flavus* and *A. parasiticus*, the most potent carcinogen found in nature (Castegnaro & McGregor 1998; Park & Liang 1993; Pittet, 1998). In 1998, a major aflatoxin epidemic in corn occurred in the Southeast, USA. Higher temperatures, drought conditions, insect damage and other factors contributed to high levels of aflatoxin contamination in corn grain (Windham & Williams, 1998). Aflatoxins are reported to cause liver damage in poultry and livestock. They lower the profitability of poultry production by decreased growth, feed conversion efficiency, egg production and break in immunity leading to heavy economic losses. There is also evidence to indicate that preharvest corn infection can occur through the corn silk (Marsh & Payne, 1984). Whereas, post-harvest contamination can occur if crop drying is delayed and if, during storage, water activity is allowed to exceed critical limits for mold growth. These fungal toxins are recognized as important constraints to human health.

Soil solarization is a relatively new mulching technique for hydrothermal disinfestation (Katan *et al*., 1976), where moist soil is covered with transparent polyethylene film during the summer (Ahmad *et al*., 1996; Stapleton *et al*., 1985) and heated by solar radiation for several weeks (Ahmad *et al*., 1996; Stapleton & Garza-Lopez, 1988). It is used to control soil-borne pests in regions with high temperature and intense solar radiation (Ahmad *et al*., 1996; Mahrer *et al*., 1987; Naot *et al*., 1987). Solarized soils frequently suppress certain soil-borne pathogens and weeds (Ahmad *et al*., 1996; Greenberger *et al*., 1987; Powles *et al*., 1988; Rubin & Benjamin, 1984; Stapleton & Garza-Lopez, 1988), especially in the top 10 cm soil (Ahmad *et al*., 1996; Ben-Yephet, 1988; Lazarovits *et al*., 1991). Soil solarization reduces the number of fungi, bacteria, nematodes, insects and weeds. It often results in increased plant growth response, yield and fruit quality (Buercky, 1988; Kaewruang *et al*., 1989; Kim & Han, 1988; Lazarovits *et al*., 1991; Sivakumar & Marimuthu, 1987) even in the absence of known pathogens (Chen & Katan, 1980; Katan, 1981; Stapleton & deVay, 1984). Solarization may affect the chemistry of the soil, increasing quantities of mineral nutrients in solution (Chen & Katan, 1980; Daelemans, 1989; Kaewruang *et al*., 1989; Stapleton *et al*., 1985) and decreasing soil salinity (Abdel-Rahim *et al*., 1988). Since soil mulching is economical, simple, safe, involves no phytotoxicity or pesticide residues (Bandara, 1987) and does not require sophisticated machines (Jacobsohn *et al*., 1980), the effect of soil solarization in the control of ear rot disease was also evaluated. The purpose of this study was to investigate the effects of soil solarization on stalk and ear rots for the management of mycotoxins in corn. Changes in soil nutrients and other soil characteristics (temperature, pH and EC) were also evaluated.

Material and Methods

Field experiments were conducted in soils naturally infested with pest and pathogens at NARC, Islamabad during 2004. Samples were collected from (10, 20 and 30 cm) soil depths with a standard 4 cm diameter core auger to examine nutrients before soil solarization.

Soil solarization technology alone and in combination with soil amendments (farm yard manure, chicken farm yard manure, neem leaves and biokhad) was used to control mycotoxins in corn by reducing soil-borne fungi and to increase the productivity as well as quality of corn grains. All plots were pre-irrigated and then mulched treatments were covered with colored (red, green, blue and black) and transparent polyethylene films (0.04 mm thick) to trap solar heat in the soil and to kill many of the damaging soil pests and weed seed. No pesticide was applied. Before mulching, temperature probes were inserted into the soil of all treatments at depths of 10, 20 and 30cm to measure soil temperature. Soil was kept moist during treatment to increase thermal sensitivity of any resting forms of pathogens and improve heat conductivity (Katan *et al*., 1976). Solarization started on May 15^{th}, 2004 and lasted for seven weeks. Polyethylene sheets were removed on July 7, 2004, one day before planting.

After the polyethylene film was removed, soil samples were immediately collected with a standard 4 cm diameter core auger. Four cores were collected per replication and bulked by three depth ranges (0-10, 10-20, and 20-30 cm). Soil samples were air dried, crushed in mortar pestle and sieved through 150 µm pores before chemical analysis. Bulked soil samples for each treatment, depth and replication were analyzed for macro- and micro-nutrients using ammonium bicarbonate-diethylene triamine pentaacetic acid (ABDT-PA) extraction (Soltanpour & Workman, 1979). Ten g of soil was extracted with 20 ml ABDT-PA solution in 250 ml conical flask and shaken for 15 min. before filtration. Undiluted extract was used to analyze the macro-elements (NO_3-N, P, K) and (1:10) dilution was used for the micro-nutrient (Zn). The pH of the soil was determined potentiometrically in a mixture of soil and distilled water (1 part soil: 1 part water, w/v). The same paste (1:1) was used for electrical conductivity (EC). Soil temperature, pH, EC and mineral nutrients (macro- and micro-nutrients) at three different soil depths (0-10, 10-20 and 20-30 cm) were analyzed in both solarized and non-solarized plots.

Weed population was observed in different treatments. Control of weeds was evaluated by counting number of weeds m^{-2} in both solarized and non-solarized plots, whereas, different diseases in corn both in stalk and ears were detected in the experimental plots. Incidence of diseases in each treatment were assessed at the time of harvest. Diseases caused by *F. verticillioides*, *F. graminearum* and *A. flavus* were scored separately on the basis of characteristic discoloration and symptoms produced. Number of ear kernels and stalks showing symptoms of the disease were counted for infection percentage. Severity of disease was assessed visually for different ear rots and stalk rot pathogens and confirmed under laboratory cultural conditions by isolation and characterization of the fungal organisms.

Soil samples were collected from different treatments and soil micro-flora was tested under laboratory cultural conditions at CDRP, IPEP, NARC, Islamabad in both solarized and non-solarized plots. Suspension (= 10^{-1} dilution) of each sample was prepared by taking 1 g in 9 ml diluent (sterile distilled H_2O) in a sterile universal tube, capped tightly and shaken for 30 minutes. Then prepared second (= 10^{-2}) and third (= 10^{-3}) dilutions in the same manner by taking 1 ml of 10^{-1} and 10^{-2} dilution to 9 ml sterile distilled H_2O and mixed thoroughly. Thus, final suspension (= 10^{-3} dilution) of each soil sample was prepared and plated on the PDA media plate with the help of micro pipette, spread with glass spreader and incubated at 22-25ºC for 3-4 days.

Yield was based on weight of shelled grains at 15% moisture by using the formula:

$$\text{Grain yield (kg ha}^{-1}\text{)} = \frac{\text{Field weight (100 - moisture \%) 0.8 x 10,000}}{\text{Area harvested x 85}}$$

where 0.8 was the shelling percentage (80% grains and 20% cob) and 85 was adjusted to 15% moisture.

Results and Discussion

A pronounced reduction in weed population was observed soon after removal of the polyethylene sheets. The treatment was still significant for 4 months after planting during the summer growing period. These results are in agreement with other findings (Rubin & Benjamin, 1983; Stapleton, 1991). Solarization controls weeds and reduces soil-borne pests, conserves moisture and improves other soil physico-chemical characteristics. In the present studies it also increased the availability of essential nutrients in the soil and hence enhanced the growth of corn plants. This is in agreement with other studies regarding increased soil nutrients following soil solarization (Chen & Katan, 1980; Rovira, 1976).

In solarized plots mean temperature at 10 cm soil depth was 11.5ºC higher as compared to non-solarized plots. This increase in soil temperature in solarized plots has also been reported by other workers from Israel (Horowitz *et al*., 1983; Jacobsohn *et al*., 1980; Katan, 1981), California (Pullman *et al*., 1981), Canada (Lazarovits *et al*., 1991), Mexico (Stapleton *et al*., 1985; Stapleton, 1991) and Pakistan (Ahmad *et al*., 1996; Zaki & Ghaffar, 1989). In the present studies, variation in temperature at different soil depths was greatly influenced by weather conditions (cloudy, sunny, rainy days with different air temperature and humidity). These observations agree with the findings of Katan (1981) and Mahrer (1979), who stated that temperatures in mulched soil vary with air temperature, humidity, radiation, wind velocity and soil characteristics.

Soil solarization was found effective for the management of soil-borne fungi, ear rots and mycotoxins in corn. Soil fungal flora was recorded at different soil depths (0-10, 10-20 and 20-30cm) in the plots treated with transparent and colored polyethylene sheets after seven weeks of soil solarization. Result revealed that transparent followed by blue sheet was the best treatments in reducing the soil-borne fungi especially at 10cm soil depth (Table 1). Results also revealed that out of four soil amendments (farm yard manure, chicken farm yard manure, neem leaves and biokhad), neem was found to be the best in reducing fungal flora especially at 10cm soil depth in the plots treated with transparent polyethylene sheets for seven weeks and thus, controlled ear rot diseases significantly (Table 2). Nematode population was tested at different soil depths (0-10, 10-20 and 20-30cm) in the solarized and non-solarized plots.

Results showed that transparent followed by blue sheet was found to be the best in reducing the nematode population significantly ($P=0.05$) especially at 10cm soil depth (Table 3). Likewise, results for weed population were obtained in the solarized plots treated with transparent and blue polyethylene films, where weeds were significantly reduced (Table 4). Weed population was also observed in the plots treated with differtent soil amendments. It was observed that neem followed by chicken farmyard manure were the best treatments in reducing the weed population significantly ($P=0.05$) in the solarized plots treated with transparent polyethylene sheets (0.04mm in thickness) (Table 5). Soil temperature was significantly increased in plots treated with transparent polyethylene sheets as well as in plots amended with chicken farmyard manure and farmyard manure at 10cm soil depth. It was observed that soil characteristics especially temperature was affected by the soil solarization applied with transparent polyethylene films especially in the upper soil layers whereas, other soil characteristics (pH and EC) were least affected by the soil amendments and soil solarization (Table 6). Weed population including *Setaria* sp. *foxtail*, *Sorghum halepens, Cyperus rotundus* and *Echinochloa colona* was controlled (98.5%) in solarized plots throughout the summer growing season. In contrast, the non-solarized plots had to be hand-weeded several times during the experimental period. The most important physical effect of soil mulching with transparent polyethylene films (0.04 mm thick) was increase in soil temperature, especially in the upper layers of the soil. With increasing soil depth soil temperature decreased (P=0.05). Average soil temperatures in the top layer of solarized plots reached 39.2ºC at 10 cm soil depth, about 11.5ºC higher than non-solarized plots (27.7ºC) (Table 6). Soil analyzed immediately after removal of the polyethylene film showed higher N-NO3 (22.2 mg kg^{-1}), P (13.5 mg kg^{-1}), K (330.1 mg kg^{-1}) and Zn (5.7 mg kg^{-1}) at the 10 cm depth treated with transparent polyethylene film (Table 7). This increase in K and Zn in solarized plots was due to high moisture contents in the soil, which increased solubility of these nutrients.

Soil solarization technology (applied with transparent polyethylene sheet) along with neem was found the most effective in reducing the incidence of corn ear rots and consequently reduced mycotoxins (fumonisins and aflatoxins) which could be applied for growing disease/ and mycotoxin free crops and to increase the productivity and quality of corn grains. We can avoid the hazardous/ poisonous effects of different chemicals on plant and animal life and thus, soil solarization along with neem could be used for the management of mycotoxins in food grains in future.

References

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

Ahmad, Y., A. Hameed and M. Aslam. 1996. Effect of soil solarization on corn stalk rot. *Plant & Soil*., 179: 17-24.

Bandara, J.M.R.S. 1987. Solarization of infested soil in plantations to control wilt and root rot in fodder *Leucaena*. *Leucaena Res. Rep*., 8: 64-65.

Bean, G.A. and R. Echandi. 1989. Maize mycotoxins in Latin America. *Plant Disease*, 73: 597-600.

Ben-Yephet, Y. 1988. Control of sclerotia and apothecia of *Sclerotinia sclerotiorum* by metham-sodium, methyl bromide and soil solarization. *Crop Prot*., 7: 25-27.

Buercky, K. 1988. Effect of transplanting and plastic mulch on yield and quality of sugar beet. *J. Agron. Crop Sci*., 161: 157-165.

Castegnaro, M. and D. McGregor. 1998. Carcinogenic risk assessment of mycotoxins. *Revue Med. Vet*., 149: 671-678.

Chen, Y. and J. Katan. 1980. Effect of solar heating of soils by transparent polyethylene mulching on their chemical properties. *Soil Sci*., 103: 271-277.

Daelemans, A. 1989. Soil Solarization in West-Cameroon: effect on weed control, some chemical properties and pathogens of the soil. *Acta-Hortic*., 255: 169-175.

Greenberger, A., A. Yogev and J. Katan. 1987. Induced suppressiveness in solarized soils. *Phytopathology*, 77: 1663-1667.

Horowitz, M., Y. Regev and G. Herzlinger. 1983. Solarization for weed control. *Weed Sci*., 31: 170-179.

Jacobsohn, R., A. Greenberger, J. Katan, M. Levi and H. Alon. 1980. Control of Egyptian Broomrape (*Orobanche aegyptiaca*) and other weeds by means of solar heating of the soil by polyethylene mulching. *Weed Sci*., 28: 312-316.

Kaewruang, W., K. Sivasithamparam and G.E. Hardy. 1989. Use of soil solarization to control root rots in gerberas (*Gerbera jamesonii*). *Biol. Fertil. Soils*, 8: 38-47.

Katan, J. 1981. Solar heating (solarization) of soil for control of soilborne pests. *Annu. Rev. Phytopathol*., 19: 211- 236.

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

Kim, J.I. and S.C. Han. 1988. Effect of solarization for control of root-knot nematode (*Meloidogyne* spp.) in vinyl house. *Korean J. Appl. Entomol*., 27: 1-5.

Lazarovits, G., M.A. Hawke, A.D. Tomlin, T.H.A. Olthof and S. Squire. 1991. Soil solarization to control *Verticillium dahliae* and *Pratylenchus penetrans* on potatoes in central Ontario. *Can. J. Plant Pathol*., 13: 116-123.

Mahrer, Y. 1979. Prediction of soil temperatures of a soil mulched with transparent polyethylene. *J. Appl. Meterol*., 18: 1263-1267.

Mahrer, Y., R. Avissar, O. Naot and J. Katan. 1987. Intensified soil solarization with closed greenhouses: Numerical and experimental studies. *Agric. Meteorol*., 41: 325-334.

Marsh, S.F. and G.A. Payne. 1984. Preharvest infection of corn silks and kernels by *Aspergillus flavus*. *Phytopathology*, 74:1284-1289.

Naot, O., Y. Mahrer, E. Rawitz, R. Avissar and J. Katan. 1987. The effect of reirrigation on the thermal regime of polyethylene-mulched soils: Experimental and numerical studies. *Soil Sci*., 144: 101-112.

Park, D. L., and B. Liang. 1993. Perspectives on aflatoxin control for human food and animal feed. *Trends in Food Sci. & Technol.,* 4:334-342.

Pittet, A. 1998. Natural occurrence of mycotoxins in foods and feeds - an updated review. *Revue Med. Vet.,* 149:479-492.

Powles, S.B., N. Charman and F. Poole. 1988. Solar heating (solarization) of the soil surface: Effect on weed control and yield of *Phaseolus vulgaris*. *Plant Prot*., 3: 31-35.

Pullman, G.S., J.E. deVay and R.H. Garber. 1981. Soil Solarization and thermal death: a logarithmic relationship between time and temperature for four soil-borne plant pathogens. *Phytopathology*, 71: 959-964.

Rovira, A.D. 1976. Studies on soil fumigation. I. Effects on ammonium, nitrate and phosphate in soil and on the growth, nutrition, and yield of wheat. *Soil Biol. Biochem*., 8: 241-247.

Rubin, B. and A. Benjamin. 1983. Solar heating of the soil: Effect on weed control and on soil-incorporated herbicides. *Weed Sci*., 31: 819-825.

Rubin, B. and A. Benjamin. 1984. Solar heating of the soil: Involvement of environmental factors in the weed control process. *Weed Sci*., 32: 138-142.

Sivakumar, M. and T. Marimuthu. 1987. Preliminary studies on the effect of solarization on phytonematodes of betelvine. *Indian J. Nematol*., 17: 58-59.

Smith, D.R. and D.G. White. 1988. Diseases of corn, pp. 701-766 In: *Corn and Corn Improvement, Agronomy Series* #18 (3rd ed.) (Eds.): C.F. Sprague and J.W. Dudley. ASA-CSSA-SSSA, Madison, WI.

Soltanpour, P.N. and S. Workman. 1979. Modification of the NH_4HCO_3-DTPA soil test to omit carbon black. Commun. *Soil Sci. Plant Anal*., 10: 1411-1420.

Stapleton, J.J. 1991. Soil solarization in tropical agriculture for pre- and post-plant applications. *FAO Plant Prod. Prot. Paper*, 109: 220-228.

Stapleton, J.J. and J.E. deVay. 1984. Thermal components of soil solarization as related to changes in soil and root microflora and increased plant growth response. *Phytopathology*, 74: 255-259.

Stapleton, J.J. and J.G. Garza-Lopez. 1988. Mulching of soils with transparent (solarization) and black polyethylene films to increase growth of annual and perennial crops in southwestern Mexico. *Trop. Agric*., 65: 29-33.

Stapleton, J.J., J. Quick and J.E. deVay. 1985. Soil solarization: effects on soil properties, crop fertilization and plant growth. *Soil Biol. Biochem*., 17: 369-373.

Windham, G.L. and W.P. Williams. 1998. *Aspergillus flavus* infection and aflatoxin accumulation in resistant and susceptible maize hybrids. *Plant Dis.,* 82:281-284.

Zaki, M.J. and A. Ghaffar. 1989. Effect of soil solarization on the reduction in viability of sclerotia of *Macrophomina phaseolina* at different field locations. *Pak. J. Sci. Ind. Res*., 32: 413-415.

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