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Efficient soil solarization for weed control in the rain-fed upland rice ecosystem

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A b s t r a c t. Weed competition causes significant damage (up to 90%) to crop yields. Weed control through chemical means in the form of herbicide is commonly used to kill weeds or inhibit their growth throughout the world. However, the use of herbicides has increased toxic residues dangerously, indiscriminately targeting organisms, the environment, and ground water and creating serious upheaval in the ecosystem. Studies were conducted through a series of experiments for five consecutive wet seasons with a variety of alternative biological solutions to control the weeds. These solutions are benign, harmless, pollution free, non - hazardous and eco - friendly and control the pre-emergence of weeds in the rain-fed, upland rice ecosystem whereas in the high rainfall coastal region of eastern India, control was effected through soil solarization. This is a method of heating the soil's surface by using transparent low-density polyethylene (LDPE film) sheets placed on the soil's surface to trap solar radiation. This raises the soil temperature to a level which is lethal for many soil borne pathogens and weed seeds, thus killing weeds before they even begin to grow.

The rise in soil temperature due to solarization by using LDPE film was significantly correlated to the soil temperature under normal conditions (uncovered) and the cumulative solar radiation (Wm^{-2}) of that day but the effect of the air temperature was found to be insignificant. A quadratic relationship was developed between temperature difference (ΔT) and soil temperature (ST) and the cumulative solar radiation (SR) for that day. The use of transparent and black LDPE sheets reduces weed growth and increases rice yield. Higher yields were found in treatments using transparent LDPE films of 200 gauges and 400 gauges for 30 days followed by black LDPE film. However, lower yields were recorded from the fields which were covered with LDPE films (both 200 and 400 gauge) beyond 30 days.

K e y w o r d s: solarization, LDPE film, rice, weed control, herbicide

INTRODUCTION

Weeds grow in cropped fields and compete with crops for water, nutrients, light and space and thus reduce crop yields significantly. Under uncontrolled situations they cause some 90% damage to the crops. In nonirrigated areas, competition between weeds and crops is largely for water whereas in irrigated or high rainfall tracts, competition is severe for nutrients. Weeds also generate formidable competition with crops for light. One of the secrets behind the high yield potential of the dwarf varieties of crop plants is that they can capture solar energy more efficiently. Reduction in crop yield has a direct correlation with weed competition. The extent of the yield reduction of rice due to weeds in India alone is estimated at around 15–20% for transplanted rice, 30–35% for direct seeded rice under paddy-field conditions and over 50% for upland rice (Pillai and Rao, 1974). The potential loss to rice production in India due to weed infestation is estimated at 15 million tonnes per annum (Chatterjee and Maity, 1990). The International Rice Research Institute (IRRI), in the Philippines undertook extensive research work to study the influence of nitrogen on the competition between rice and weeds and reported that the grain yield decreased as the amount of nitrogen applied increased. It was reported that there was a 95% yield reduction of the rice cultivar 'IR-8' when 120 kg N ha^{-1} was applied and it appears that in fields overrun with weeds, the addition of fertilizers favoured the weeds more than it did the rice crop. Further data reveals that nitrogenous fertilizers should not be used before weeds have been brought under

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control. Weeds remove plant nutrients more efficiently than do crops (Rao, 1983).

Recently, weed control through chemical means in the form of herbicides has been routinely used to kill plants or inhibit their growth in many parts of the world. However, intensive herbicide use has raised serious concerns about their effect on non-target organisms, the environment and ground water since it may create serious upheaval in the ecosystem. The indiscriminate use of herbicides may build up indestructible residues in the soil, rendering it barren and unproductive (Khan *et al*., 2000). The use of herbicides has added toxic residues both to the soil and the ground water to dangerously high levels. Apart from water and soil pollution and the contamination of food grains and food products with toxic residues, there are also environmental hazards regarding the over-use of herbicides for killing weeds. Some herbicides retard root development and develop dangerous effects in the plants (Khan *et al*., 1997). Hence there is a continuous search for newer, non-hazardous and eco-friendly methods which may sustain the soil's health and ecology, eliminate soil and water pollution, reduce the cost of input and increase income for the farmer.

Soil solarization is a method of heating the soil's surface by using transparent polyethylene sheets (LDPE film) placed on the soil surface to trap solar radiation. This raises the soil temperature to levels lethal for many soil borne pathogens and weed seeds, thus killing weeds before emergence. This technique can be effectively used in hot areas (Anonymous, 1994). This is gaining increased attention globally and experiments have been conducted since late 1970 in countries like the U.S.A, Greece, Italy, Jordan and Israel etc. Maximum weed loss for a longer period due to a longer period of solarization is found. Solarization for 67 days in Torino (Italy) resulted in a reduction of the 'Dicot' weed by 99% and of the 'Monocot' weed by 94%. Increases in peanut yields up to 52% by weed reduction, due to solarization, were reported in Jerusalem and a 300% increase in the tomato yield in Jordan due to the reduction in weeds as a result of solarization was also reported. Streack *et al*. (1997) working on the carrot at the Central Region of the Rio Grande do Sul State, South Brazil, found that solarization increases the maximum temperature by 5.2 and 4.1°C at the 2 and 5 cm soil depths, respectively. USEPA (2000) has recommended solarization as an alternative to methyl-bromide (used in the fumigation of the tomato) an ozone depleting chemical. In Bangladesh, it has been reported that solarization increased the yield of spring rice from 1 to 1.5 t ha^{-1} at one location and 2.5 to 3.8 t ha^{-1} at another location. Combined with seed treatment, the increased yield was 2.0 and 4.0 t ha^{-1} at both locations (CIMMYT, 2000). Similar results were observed per plant per m^2 and germination percentage.

The present investigation was carried out in the upland ecosystem over five consecutive wet seasons through a series of experiments to control weeds and the pre-emergence of weeds with a variety of alternative biological solutions which are benign, harmless, pollution-free, non-hazardous and eco-friendly; the investigation was carried out through solarization in the high rainfall coastal region of eastern India.

MATERIALS AND METHODS

Experiments were conducted in the rain-fed, upland coastal eco-system at the eastern region's Water Technology Centre & Research Farm, Mendhasal (Bhubaneswar - Orissa), India over five consecutive wet seasons (June-October) of 1994 to 1998. The soil is acidic (pH 5.2) in the Bay of Bengal coastal belt, situated on the transverse point of 85°52' longitude and 20°15' latitude at an average altitude of 25.90 m a.s.l. The experimental soil has about 65.14, 16.60 and 18.26% sand, silt and clay, respectively. The other soil characteristics are presented in Table 1. The experiment

T a b l e 1. Physical-chemical characteristics of experimental soil

No.	Characteristic	Value
1.	Bulk density (in situ)	1.55 g cm^{-3}
2.	Organic matter	0.40%
3.	Void ratio	0.71
4.	−33 MPa moisture	14.30%
5.	−1500 MPa moisture	4.50%
6.	Available N	220 kg ha^{-1}
7.	Available P	11 kg ha^{-1}
8.	Available K	122 kg ha^{-1}

was laid out in a randomised block design. The annual rainfall (average out over 100 years) of this region is 1432.4 mm which provides a favourable and optimum environment for all types of weed growth. The seven treatments given below were replicated three times in a randomised block design. The gross plot size of the experiment was 5.0x4.0 m^2 and the net plot size was 4.6 x 3.2 m^2. Rice cultivar IR-36 was sown at the seed rate of 70 kg ha^{-1}. Transparent, low-density polyethylene (LDPE film) sheets were placed before ploughing. The LDPE film was removed and ploughing was done before sowing. The treatments were selected to standardise techniques in terms of the type of film, the thickness of the film and the number of days the film covered the soil. The following treatments were carried out before sowing:

T_1 – Unweed check (Control).

T_2 – Weeded check (Hand/mech. weeding).

T_3 – Transparent LDPE film of 50 thickness (200 gauge) for 30 days.

T_4 – Transparent LDPE film of 50 thickness (200 gauge) for 45 days.

T_5 – Transparent LDPE sheet of 100 μ thickness (400 gauge) for 30 days.

T_6 – Transparent LDPE sheet of 100 μ thickness (400 gauge) for 45 days.

T_7 – Black LDPE film of 100 μ (400 gauge) for one week before planting (Smothering).

The soil temperature at the two soil depths of 5 and 10 cm were recorded by soil thermometers at four time intervals (i.e., 8.00 a.m., 12.00 noon, 2.00 p.m., 4.00 p.m.) a day during the solarization period. The crop and weed parameters were also recorded. To evaluate the effect of the type of film, ambient soil temperature and solar radiation on changes in temperature, a multiple regression analysis was done between changes in temperature, soil temperature, air temperature, and cumulative solar radiation. The regression equation identifies insignificant factors, deletes them and finally gives the relationship between all significant factors.

RESULTS AND DISCUSSION

Thermal regime of the soil

Figure 1 depicts the temperature at the two depths of 5 and 10 cm in the control without covering, then covered with transparent film (TP) and then covered with black film (BP) for crop year 1997, although the trend was the same for all five years. A maximum of four temperature values – recorded daily – were considered for comparison since maximum temperature is important from the point of view of killing germination in weed seeds. It is evident from the figure that the soil temperature at the 5 cm depth under the transparent film mulch rose by 10–15°C up to the 15th of June after which the difference came down to 5–8°C. The difference in soil temperature at the 10 cm depth during this period was 10–12°C. During this period, the soil temperature was above 45°C at the 5 cm depth and above 40°C at the 10 cm depth. As the monsoon set in around 15 June, solar radiation reduced but still the soil temperature remained around 35°C during the rest of the period. Since most weed seeds do not remain viable for germination at this temperature, the transparent LDPE cover (mulch) will kill the germination viability of all weed seeds located up to the 10 cm depth.

In the case of the black film mulch, the temperature at the 5 cm soil depth was closer to the temperatures observed in the transparent film mulch. However, at the 10 cm soil depth, it was much less. Thus black film will not be as efficient in killing the germination viability of weed seeds located up to the 10 cm soil depth. This indicates that for heating the soil, a transparent LDPE film mulch should perform better than a black film mulch.

The rise in soil temperature due to solarization by using LDPE film is significantly correlated to soil temperature under normal conditions (uncovered) and the cumulative solar radiation (Wm^{-2}) of that day but the effect of air temperature was found insignificant. A quadratic relationship was developed between the temperature difference, (DT) and the soil temperature (ST) and the cumulative solar radiation (SR) of the day for all four solarization treatments. The relationships are:

5 cm soil depth with transparent film cover,

$$\Delta T = -3.65 \cdot 10^3 + 2.36 \cdot 10^2 \cdot ST - 2.70 \cdot 10^{-3} \cdot SR - 3.84 \cdot ST^2 + 2.20 \cdot 10^{-2} \cdot ST \cdot SR + 4.30 \cdot 10^{-7} \cdot SR^2$$

$r = 0.86$

10 cm soil depth with transparent film cover

$$\Delta T = -1.52 \cdot 10^3 + 93.64 \cdot ST - 1.46 \cdot SR - 3.30 \cdot 10^{-2} \cdot ST^2 - 2.20 \cdot 10^{-4} \cdot ST \cdot SR + 1.10 \cdot 10^{-6} \cdot SR^2$$

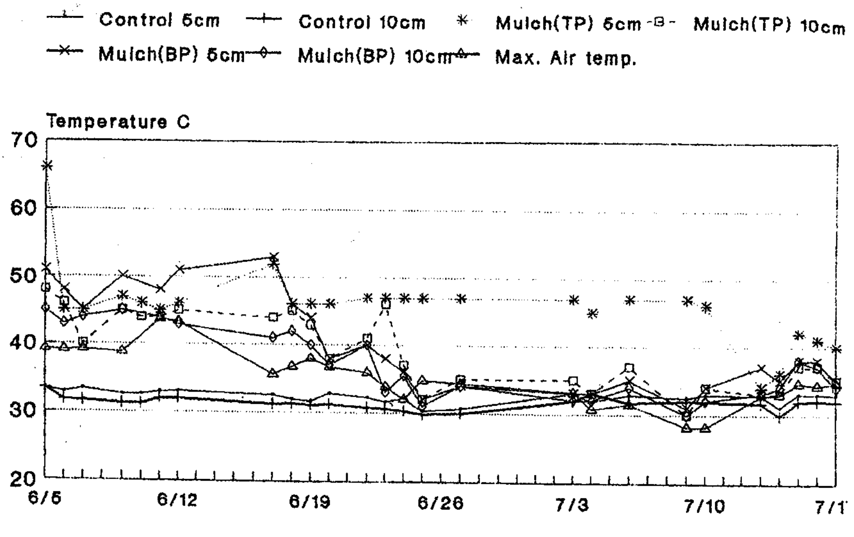

Fig. 1. Maximum soil temperature at different depths under mulch and non mulch conditions in June and July 1997.

r = 0.87

5 cm soil depth with black film cover

$$\Delta T = -4.36 \cdot 10^3 + 3.00 \cdot 10^2\ ST - 16.70 \cdot SR - 5.15 \cdot ST^2 + 0.55 \cdot ST \cdot SR + 7.10 \cdot 10^{-8} \cdot SR^2$$

r = 0.86

10 cm soil depth with black film cover

$$\Delta T = 2.36 \cdot 10^3 - 1.48 \cdot 10^2 \cdot ST + 2.31 \cdot SR + 4.9 \cdot 10^{-2} \cdot ST^2 - 2.20 \cdot 10^{-2} \cdot ST \cdot SR + 2.10 \cdot 10^{-5} \cdot SR^2$$

r = 0.37.

As expected, the correlation for the 10 cm soil depth with black film cover was insignificant. This is due to the poor radiation transmission quality of black film (Khan, 1988). But a significant correlation was found for the soil temperature difference with transparent film cover at both depths. These equations can be used for deciding the best period for solarization to get the maximum advantage from heating the soil to kill the germination viability of weed seeds and harmful microbes.

Effect of solarization on weeds

The prevalent weed flora in the plots were ; (i) Grasses: Monocots having long, narrow, two-ranked flat leaves with parallel venation and round hollow stems: *Echinochloa colonum* L. and *Cynodon dactylon* (ii) Sedges: Similar to grasses but have three-ranked leaves and triangular solid stems. They frequently have modified rhizomes adapted for storage and propagation: *Cyperus rotundus, L.* and *Cyperus iria* L. (iii) Broad Leaved: Dicots with their neat venation of leaves and easily identified: *Eclipta alba* Hassk, *Euphorbia hirta*, *Phyllanthus niruri* and *Ageratum conyzoides* L. etc.

Table 2 presents the weed dry weight and weed count under different treatments. There are significant treatment effects on the dry weight of weeds and the weed count of narrow leaved and broad leaved weeds except for sedges. There is drastic reduction in weed growth due to solarization. The trend was similar over the whole five years. The germination viability of weed seeds in the black LDPE and hand weeding might not be affected as adversely as in the transparent LDPE sheets. Soil warms up faster under clear plastic since the incident short wave radiation is transmitted through it and absorbed directly by the soil (Khan, 1983).

Effect on yield parameters and yield

The yields and yield components of rice as affected by solarization on crop parameters are presented in Table 3. From the table showing five years' accumulated data (1994 to 1998) it is evident that the rice yield in the treatment with the transparent 400 gauge LDPE for 30 days (T_5) is significantly higher than the rice yield in the treatment with the transparent 200 gauge LDPE for 30 days (T_3) and the treatment with the black 400 gauge LDPE (smothering) for one week (T_7). However, transparent 400 and 200 gauge LDPE for 45 days (T_4 and T_6) produced lower yields. There is a significant effect on yield level from the thickness of the film used and the yield is also affected by the duration of coverage. It seems that covering the soil with LDPE sheets beyond 30 days may be detrimental to crop growth and yield due to the harmful effects of higher temperature regimes on the growth of beneficial microbes. The temperature of the soil and its associated and antagonistic effect also play an important role in the survival of microbes. The maximum microbe count was reported in spring, the lowest being in the summer and winter (Sarkar and Khan, 2002). Most microorganisms prefer a temperature range of 25 to 35 C (Chang *et al*., 1977; Bhatt, 1999). The soil temperature rose to 45 C at the 5 cm soil depth and above 40 C at the 10 cm soil depth during the experiments.

From the above studies it is evident that weeds can be minimised using LDPE film which is ecologically friendly

T a b l e 2. Weed dry weight at the panicle initiation stage

Treatment	Weed dry weight (kg ha^{-1})	Weed counts m^{-2}		
		Narrow leaved	Broad leaved	Sedge
T_1 – Unweeded check (Control)	464	123	41	14
T_2 – Weeded check (Hand/mech.weeding)	308	89	21	11
T_3 – 50 LDPE for 30 days	161	64	17	5
T_4 – 50 LDPE for 45 days	222	156	28	9
T_5 – 100 LDPE for 30 days	120	63	16	4
T_6 – 100 LDPE for 45 days	171	274	36	9
T_7 – 100 Black LDPE	248	79	21	–
C.D at 5%	51.3	39.4	10.2	NS

T a b l e 3. Yield and yield components of rice (CR-1009) as affected by weed control treatments

Treatment	Grain yield (kg ha^{-1})	Grain/ Panicle	Chaff/ Panicle	Panicle length (cm)	Plant height (cm)
T_1 – Unweeded check (Control)	1095	85	10	18.65	79.95
T_2 – Weeded check (Hand/mech. weeding)	1968	66	08	17.16	69.38
T_3 – 50 LDPE for 30 days	2457	75	11	18.13	75.98
T_4 – 50 LDPE for 45 days	1739	82	10	18.20	73.66
T_5 – 100 LDPE for 30 days	2577	84	11	18.25	76.29
T_6 – 100 LDPE for 45 days	1466	88	09	18.51	73.63
T_7 – 100 Black LDPE	2348	72	14	18.50	83.32
C.D at 5%	319.48	NS	NS	NS	NS

and harmless to both the soil and the environment and saves the ecosystem from dangerous pollution. Crop yields are reasonably good in the rain-fed upland coastal ecosystem due to weed-control.

CONCLUSION

It can be concluded that solarization is effective in weed control and improves yield levels. For effective solarization, transparent LDPE film of 50 thickness should be used to cover the soil for 30 days. The period of cover should be decided on the basis of normal soil temperature, solar radiation and the temperature required to kill the weed seeds and harmful microbes.

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