

Plastic mulch cultivation of rice (*Oryza sativa*) in India in light of dwindling water resources

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ABSTRACT

A field investigation was carried out during 2 winter seasons (*rabi*) of 2012–13 and 2013–14 at the ICAR-Directorate of Rice Research, Hyderabad, Telangana to assess the impact of mulching and moisture regime treatments on transplanted rice (*Oryza sativa* L.) productivity and economics. Results revealed that saturation moisture regime affected 35% irrigation water economy but reduced rice grain yield by 7.8% (0.38 t/ha) on account of greater weed pressures over standing water rice culture (4.86 t/ha). Saturation moisture when combined with plastic mulching, reduced yield penalty by 56.6% (0.22 t/ha), thus became at par with transplanted rice with standing water. Additional irrigation water economy (23%, i.e. 15 cm) and elimination of weeding were seen in plastic mulch-transplanted rice. There was minimal weed biomass production (4.9% of standing water 125.3 and 3.1% of saturation moisture: 194.5 g/m²). Transplanted rice with standing water was highly economical with net profit of ₹43,220/ha to saturation moisture (₹31,360/ha) when irrigation water is free and upon pricing of irrigation water @ ₹400/ha-cm, saturation moisture-transplanted rice became more economical than standing water. High cost of plastic mulch (₹23,000/ha) masked the gains in irrigation water, saving weeding cost and higher yield irrespective of irrigation water pricing. Saturation moisture-transplanted rice could be adopted without any challenges but for adding plastic mulch to saturation moisture, reducing its cost and evolving biodegradable plastics (making environment friendly) including N management options need to be evolved.

Key words: Irrigation water, Plastic mulching, Rice, Saturation moisture, Standing water

Rice is the most important staple crop of India and it accounted for 40% (111.01 million tonnes) of the total foodgrain production (277.49 million tonnes) in 2017–18 (GoI, 2018). Though rice has began its journey as a rainfed direct-seeded crop, its transplanted culture in puddle soils under assured irrigation throughout the year (*kharif*, *rabi* and *zaid* seasons) has gained prominence and has stable yields and further scope lies to enhance it through input management. Accordingly, the share of irrigated rice in total rice acreage has increased from 31.7% in 1950–51 to 60.1% in 2014–15 (GoI, 2017). Surplus manpower available in the country at menial wages since independence to early 1980s had favoured labour-intensive transplanted rice (TPR) culture. Planned irrigation facilities development with huge money investments over five-year plans in the country promoted TPR culture. Reduced weed menace in TPR owing to puddling and continuous standing water

(Kent and Johnson, 2001) was also one of the reasons for its preference. However, over the time, per capita water availability has come down from safe limit of 1,700 m³ in 2001 (1,820 m³) to 1,545 m³ by 2011 and is slated to reach 1,140 m³ by 2030 (Sengupta, 2018). Accordingly, the share of water for agriculture is anticipated to decline from 88% in the year 2000 to 72% by 2050 (GoI, 2009). Reduced water supplies call for rational and efficient use of water by all sectors. Rice is the highest water consumer in the country with an estimated water foot print of 432.9 billion m³ including percolation losses during 2000–04 (Chapagain and Hoekstra, 2011). Thus, the luxury of maintaining standing water in puddle TPR is impossible in the coming years and more so during post-monsoon seasons (*rabi/zaid*) as it is devoid of rains. Non-*kharif* season accounts for 13.1% of total rice production during 2017–18 (GoI, 2018). In this context, water efficient rice-production technologies are evaluated that revolve around 3 approaches, i.e. (i) saturated soil culture through system of rice intensification, alternate wetting and drying with little water economy (Peng *et al.*, 2006); (ii) aerobic rice culture with irrigation at critical stages (Boumann *et al.*, 2002) and (iii) ground cover

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rice-production systems (GCRPS) involving mulches (Tao *et al.*, 2006) and drip irrigation (He *et al.*, 2013). Studies indicate that GCPRS besides water saving also contributes to weed management, thermal regulation (Kasirajan and Ngouajio, 2012) and also for reducing green-house gas emissions (Fawibe *et al.*, 2019). Plastic mulching can be easily managed during non-rainy season irrigated crop than rainy season crop. In India, studies pertaining to the third approach, i.e. GCPRS, are not attempted till date. Keeping in view the dearth of information, field investigation was carried out during winter season (*rabi*) (December–April) to assess the utility of plastic mulch cultivation of TPR with saturation moisture regime in contrast to its traditional standing water culture for water economy, weed management, productivity and profitability.

MATERIALS AND METHODS

The field experiment was conducted during the winter season (*rabi*) of December 2012–April 2013 and December 2013–April 2014 at the ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telangana (19° N, 74° E, 700 m above mean sea-level). The experimental region has a semi-arid climate. Rainfall in 2014 was 153.6 mm in 8 rainy days (most of it was received in April: 112.3 mm) was higher than 2013 (32.2 mm in 4 rainy days). A day with >2.5 mm rain/day is taken as rainy day. Mean maximum and minimum temperatures during crop season (January–20 April) was 31.9 and 16.8 (2013) and 33.6 and 19.0 (2014). The soil was clay loam in experimental field (Vertisol; Typic Pellustert) with a 7.8 pH at the start of study in December in its top 20 cm layer soil. The soil was analysed as per Jackson (1973) and contained 0.67% and 0.66% organic carbon and low available nitrogen (268.1 and 261.3 kg/ha KMnO_4 -extractable N), medium available phosphorus (18.2 and 17.9 kg/ha 0.5 M NaHCO_3 -extractable P) and potassium (378.2 and 379.8 kg/ha NH_4OAC -extractable K) in 2012 and 2013 respectively. The soil with a bulk density of 1.40 g/cc has field capacity (FC) and permanent wilting point (PWP) moisture of 23 and 13%. Four mulching and moisture regime treatments were evaluated in randomized complete block design with 6 replications per treatment. The treatments were: 5 cm standing water (SW), saturation moisture (SM), black and transparent polythene mulching (PM) with SM. Experimental field was prepared thoroughly by 3 times puddling with power tiller in standing water (water was let into field and 2 cm standing water was maintained for 4 days prior to start of puddling) followed by its precise levelling and field layout. On such levelled field, plastic film mulches (1.4 m width, 15 m length and 25 gsm thickness) as per treatment were spread on the field with inward folding of plastic sheets into the soil and placing of wet soil on all sides so as to

form a bund of 15 cm height with a channel following the plot of 15 m length (Fig. 1a) on all sides. A wooden marker with 6 pegs at a distance of 20 cm was fabricated and pressed into the PM sheet at 10 cm spacing. Into these holes, 25 days seedlings of rice variety 'MTU 1010' were manually transplanted on 30 December during both the years. Phosphorus and potassium fertilizers @ 26.4 kg P and 36 kg K/ha were applied through single superphosphate and muriate of potash in the last puddling uniformly in all treatments. Nitrogen as per treatment through prilled urea (150 kg/ha) was broadcast applied on 5, 30 and 45 days after transplanting (DAT) in unmulched crop, whereas in mulched treatments, 100 kg N was applied basal along with P and K. Remaining N was mixed with irrigation water at plot @16.7 kg/ha at 30, 40 and 50 DAT. Two manual weedings were done on 20 and 40 DAT. Weeds were collected from 0.5 m² quadrat along with their roots at 2 locations per treatment. Root portions were cut and the remaining above-ground biomass of weeds was oven dried at 60°C for 48 h and their weight was recorded treatment-wise. Weeding was done manually and 20, 30 and 2 man-days were used in standing water, saturation moisture (SM) and PM + SM regime treatments, respectively, and a labour cost of 300/day was used. Water was applied to each plot through PVC pipes of 10 cm diameter to maintain SM in mulched treatments and standing water (5 cm) was maintained from 3 DAT. Irrigation water (IW) of bore well lifted by electrical pumpset was applied through water meter treatment-wise and was summed up for entire crop season (transplanting to harvest) and reported as ha-cm. Saturation moisture regime was maintained by alternate day irrigation. In standing water regime, water is let in whenever water depth is coming below 4 cm depth at bench mark point kept in each plot. Irrigation was stopped from 5 April onwards during both the years. Enough precautions were taken to arrest movement of water from one to other treatment plot. Water productivity (kg/ha-cm) was worked out as a function of grain yield (kg) to irrigation water applied (ha-cm). Soil thermometers were installed at 10, 15 and 30 cm depth to measure temperature in all the treatments. However, little differences in treatments were observed, hence data not presented. Benefit : cost (B : C) ratio was worked out as ratio of gross income (net income + cost of cultivation) to cost of cultivation (₹/ha). Growth was recorded in non destructive way through recording plant height and tiller numbers in PM as well as non-PM treatments. Yield attributes from 10 randomly selected hills and yield (straw and grain) from net plot (kg/ha) were recorded. Crop was harvested at physiological maturity on 20 April in both the years. In the calculation of economics, minimum support price of rice grain (₹14,500/tonne) and market price of straw (₹2,500/ tonne) were used. For plastic

mulch treatment imposition in field, 10-man days (₹3,000) and plastic cost of ₹20,000/ha were used. Need-based plant-protection measures were taken for successful cultivation of crop without any yield penalties. For saturation moisture regime irrigation, 7 man-days were used. Economics were worked out for 2 scenarios, i.e. no cost of water and with water cost including water lifting charges of ₹400/ha-cm. The analysis of variance (ANOVA) was done in randomized complete block design. The significance of treatment differences was compared by critical difference (CD) at 5% level of significance ($P=0.05$) and statistical interpretation of treatments was done as per Gomez and Gomez (1984). As data were similar during both the years, pooled analysis was carried out and year \times treatment effects were not significant and pooled data were presented.

RESULTS AND DISCUSSION

Weather was highly congenial for rice cultivation. The marker used for making holes in plastic sheet and transplanting, established seedling and harvesting without any weeds present on ground are shown in Fig. 1a-c. During the rice growing period, 32.2 and 153.9 mm rainfall was



Fig. 1a. Marking on plastic and transplanting of rice on plastic mulches.



Fig. 1b. Established rice seedling in plastic mulching and standing water.



Fig. 1c. Harvesting of plastic mulched rice (devoid of weeds) as compared to weedy standing water crop.

received in 2013 and 2014. However, 12.3 mm of 2014 rain was during April when IW was stopped. The mean temperatures were slightly low in 2014 than 2013 and thus crop required 5 cm less irrigation than 2013. Thus crop was raised on irrigation completely.

Growth and yield attributes of rice

Growth and yield attributes data of rice as influenced by mulching and moisture regimes are given in Table 1. Data indicated significant differences in number of panicles only. Without mulch, rice has produced 23.3 more number of panicles/m² with standing water than that with saturation moisture (343.9). Mulching has bridged the above differences in panicle numbers/m² between saturation and standing water moisture regimes. In saturation moisture regime panicles production was increased with black and transparent plastic mulch by 12.2 and 14.6/m². Thus, black and transparent mulches at saturation moisture had panicles at par as that of standing water without mulch. Further transparent polythene mulched rice had significantly more number of panicles than no mulch - saturation moisture regime. Grains/panicle and test weight among yield attributes and plant height as growth attribute were not influenced by mulching and moisture regimes. Rice plants attained a mean height of 84.63 cm and produced 107.2 grains/panicle and had a test weight of 23.95 g. The increases in panicles production could be still higher if N application was done in splits in plastic mulching. Here N was applied basal with small quantities of urea application with irrigation water.

Grain and straw yields

Grain and straw yields of rice were greatly affected by mulching with moisture regimes (Table 1). Saturation

Table 1. Growth, yield attributes and yield of rice as influenced by mulching and moisture regime (pooled 2 years data)

Mulching and moisture regime	Plant height (cm)	Panicles/m ²	Grains/panicle	Test weight (g)	Yield (t/ha)	
					Grain	Straw
No mulch in saturation moisture (SM)	83.1	343.9	105.3	23.9	4.48	6.60
Black mulch in SM	82.5	356.1	108.1	24.0	4.67	6.83
Transparent mulch in SM	86.2	358.5	106.5	23.9	4.72	6.94
No mulch with 5 cm standing water (SW)	86.5	367.2	109.0	24.0	4.86	7.11
SEm±	2.04	4.47	1.81	0.13	0.047	0.084
CD (P=0.05)	NS	13.47	NS	NS	0.143	0.254

moisture regime has significantly reduced the rice grain yields over the standing water regime under no mulch situation. Saturation moisture regime resulted in 0.38 and 0.51 t/ha lesser grain and straw yield than that of standing water (4.86 and 7.11 t/ha). These significant losses in grain and straw yields under saturation moisture regime as compared to standing water were nullified statistically with transparent plastic mulch. However, both plastic mulches remained statistically at par with each other. These differences in grain yield came on account of similar differences in panicle productions. The similar yields of conventional flooded and plastic mulched-saturation regime rice of the current study support the findings of Tao *et al.* (2006).

Water economy

Water use of rice was significantly influenced by mulching and moisture regimes (Table 2). Traditional rice cultivation with standing water used 100 cm irrigation water from transplanting to harvest. Shifting to saturation moisture regime maintenance from standing water resulted in reduction in irrigation water by 35 cm. These reductions in irrigation water for rice under saturation moisture regime were further lowered by 15 cm with polythene mulch. The water savings in saturation moisture and plastic mulch were ascribed to drastic reductions in evaporation as compared to that from 5 cm standing water and saturated moisture regime respectively. The evaporation losses of water

(mm/day) increased with time from the lowest of 4 mm in January to 5 mm in February to 6 mm in March and finally to the highest of 7.5 mm/day in April as per weather station data at the study site. These evaporation losses averaged 5 mm/day for the active growth phase of rice (January–March) sums up to 46 cm. If we add April evaporation also (16 cm), 62 cm evaporation loss was there for the study site. There are also reductions in seepage losses to some extent with saturation moisture maintenance as compared to standing water. No weed biomass was produced under plastic mulch and also by way of reducing evapo-transpiration loss of water from weeds as compared to SM alone has contributed to the irrigation water economy. A reduction in evaporative loss of water in rice cultivated with plastic mulch as compared to no mulch rice reported by Liang *et al.* (1999) and Allen *et al.* (1998) supports the current study findings of low irrigation water need under mulch. On account of 35 and 50 cm of water savings by SM and SM + PM treatments with a small reduction in grain yields, i.e. 0.38 and 0.17 t/ha, respectively, resulted in 41.8 and 93.2% enhanced water productivity over standing water rice culture (48.6 kg/ha-cm). A study in Xinjiang province, China by He *et al.* (2013) on plastic film mulch rice cultivation recorded significantly higher water productivity than no mulch rice both with furrow irrigation. They also observed doubling of rice water productivity with drip irrigation as compared to its conventional flooding. The

Table 2. Water use, water saving, water-use efficiency, weed biomass and weeding labour requirements in rice as affected by plastic mulching and moisture regime (pooled data of over 2 years)

Treatment	Mean water use (cm)*	Water saving (cm) over No mulch and standing water	Water productivity (kg/ha-cm)	Weed dry biomass (g/m ²) from 2 weedings**	Relative weed biomass (%)	Man-days needed for weeding***
No mulch in saturation moisture (SM)	65	35	68.9	193.0 (13.91)	154.0	30
Black mulch in SM	50	50	93.4	5.8 (02.51)	4.6	2
Transparent mulch in SM	50	50	94.4	6.5 (02.65)	5.2	2
No mulch with 5 cm standing water (SW)	100	–	48.6	125.3 (11.22)	100.0	20
SEm±	3.42	–	1.87	(0.0116)	–	–
CD (P=0.05)	10.3	–	5.63	(00.35)	–	–

*From transplanting to harvesting; **Figures in parentheses are ($\sqrt{\times +0.5}$) transformed values; *** Compared to no mulch with 5 cm standing water.

current study findings of higher water productivity with PM and SM regime when compared to no mulch and standing water regime are in tune with the above findings. In the current study, nursery and land preparation irrigation water was not accounted for; which was common to all treatments (20 cm). If added to the irrigation water requirement of each treatment, the values given in Table 3 will increase by 20 cm and accordingly the irrigation water productivity will come down to 37.33, 52.7, 66.71 and 67.4 kg/ha-cm in standing water, saturation moisture, black and transparent polythene mulches respectively.

Weed growth

Weed biomass and labour required for weeding in rice were significantly influenced by mulch and moisture regimes (Table 2). Plastic mulch virtually arrested the weed growth irrespective of its colour (black/transparent) and thus excluded the need for weeding operations (only 2 labours/ha used). Except the weeds emerged within the hill of rice from gaps in the holes of plastic, no scope lied for the weeds to come up under plastic mulch treatments. Any germinated weeds below the mulch died quickly on account of lack of sunlight for photosynthesis. Complete weed control achieved with polythene mulching in tomato by Anzalone *et al.* (2010) supports the current research findings. In saturation moisture regime devoid of mulch, weed flora of rice crop was more diverse than that with no mulch-standing water treatment. Accordingly, no mulch-saturation regime rice showed 54% higher weed biomass than that with no mulch-standing water regime from 2 weedings (125.3 g/m²). More weeds emerged in no mulch-saturation regime even after 2 weedings that however were not reported. The transformed data of weed biomass ($\sqrt{x + 0.5}$) showed significant differences between mulched and no mulch treatments. Thus, on account of higher weed biomass, 10 additional man-days were required for 2 weedings in no mulch-saturation regime than no mulch-standing water regime rice (20 man-days). Mulches had little weed pressure, as evident from the weed biomass recorded which was only 4.9 and 3.2% that of standing water and saturation moisture

regime, respectively. The weed-free situation of rice crop under plastic mulch at harvesting than weedy standing/saturation moisture rice crop at harvest time is shown in Fig. 2c. The reductions in weed biomass due to plastic mulching of current study confirm the findings of Aimrun Wayayok *et al.* (2014) on system of rice intensification farming with mulches.

Economics

Economics of rice cultivation were assessed from enhanced yield, reduced water consumption, additional costs from plastic mulch and labour inputs for weeding and irrigation aspects significantly influenced by mulch and moisture regimes (Table 3). Cost of cultivation was least for traditional rice cultivation with standing water when irrigation water was not priced (₹45,000) and when irrigation water was priced (₹400/ha-cm), it became the costlier by ₹40,000. In saturation moisture regime, additional costs were incurred for weeding (10 man-days) and frequent irrigations (7 man-days) and thus cost of cultivation increased by ₹5,100 over standing water rice. In plastic mulch with saturation moisture, cost of plastics (₹20,000) and labour for its laying/careful planting (15 man-days) were additional costs over standing water rice culture. However, it has reduced cost on weeding (2 man-days required for weeding in contrast to 20 man-days of traditional rice). Thus it showed ₹19,100 and ₹3,900 higher and lower cultivation cost than traditional rice without and with price for irrigation water. Net income and benefit : cost (B : C) ratio were highest with traditional cultivation when irrigation water was free and saturation moisture regime had highest net income and B : C ratio when irrigation water was priced. Plastic mulch remained less profitable in both situations, i.e. free and priced water to standing water and saturation moisture. The low income of plastic mulch was ascribed to higher costs incurred for plastics. In the current study, life of plastics was taken as single season. If we take higher life period for plastics (2–4 seasons), then their cost gets decreased and could become more profitable. On the other-hand, reducing the cost of plastics by

Table 3. Economics of rice cultivation as affected by mulching and moisture regime

Mulching and moisture regime	Cost of cultivation (₹×10 ³)		Net returns (₹×10 ³)		Benefit : cost ratio	
	Free water (A)	Priced water* (B)	A	B	A	B
No mulch in saturation moisture (SM)	50.1	76.0	31.36	5.36	1.63	1.07
Black mulch in SM	64.1	84.1	20.69	0.69	1.32	1.01
Transparent mulch in SM	64.1	84.1	21.69	1.69	1.34	1.02
No mulch with 5 cm standing water (SW)	45.0	85.0	43.22	3.22	1.96	1.04
SEm±	–	–	1.52	0.51	–	–
CD (P=0.05)	–	–	4.59	1.50	–	–

* Price of water (₹/ha-cm) including electricity for lifting ground water: 400.

use of biodegradable one with single season use could make their use more economical and ecologically benign.

It is concluded from the study that shift to saturation moisture regime cultivation of rice could affect a 35% savings in water-use when compared with standing water rice cultivation and these water savings translates into profits when irrigation water was priced. Plastic mulch increased in irrigation water savings by 23% as compared to saturation moisture regime, but proved uneconomical on account high money investments. Least cost and ecologically benign plastics that are biodegradable may make mulch profitable and contribute to water-wise rice cultivation in the country. *Rabi* season without rains was ideal for plastic mulch rice cultivation.

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