Management of Organic Mulching in Agriculture for Soil Moisture Conservation and Vegetable Productivity: A Field Evaluation

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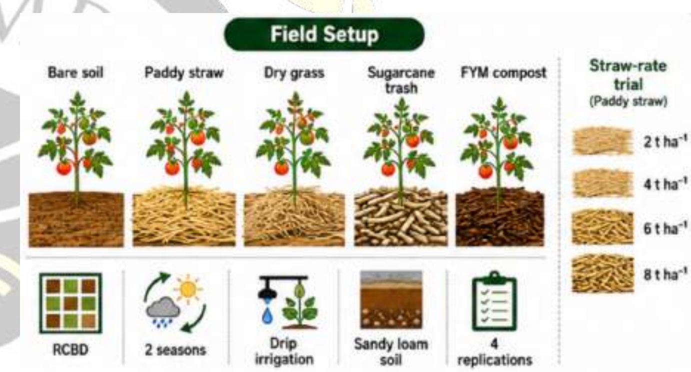
Abstract— Soil moisture is the primary constraint on vegetable productivity in rainfed and irrigation-limited systems, and organic mulching offers a low-cost route to conserving it. This study evaluated the management of four organic mulch materials — paddy straw, dry grass clippings, sugarcane trash and farmyard-manure-based compost — against a bare-soil control for their effect on soil moisture, temperature, weed suppression and tomato productivity over two cropping seasons. Straw mulch at 6 t ha^{-1} retained the highest soil moisture (18.9% v/v versus 12.4% for control) and reduced soil-temperature amplitude by 3.4 °C. Marketable tomato yield rose from 32.6 t ha^{-1} under bare soil to 46.8 t ha^{-1} under straw mulch (+43.6%), while irrigation water-use efficiency improved by 41.2% and weed dry weight fell by 71.5%. Mulch amount showed a dose-response up to 6 t ha^{-1}. Organic mulching, properly managed by material and rate, materially improves both water conservation and vegetable yield.

Keywords: organic mulch; soil moisture conservation; water-use efficiency; vegetable productivity; tomato; weed suppression

Introduction

Water is the limiting resource in most vegetable production, and the loss pathway that is easiest to interrupt is direct evaporation from the soil surface. In an unmulched field a large fraction of stored soil water leaves through the top few centimetres before the crop can use it, and in rainfed or deficit-irrigated systems that loss translates directly into reduced yield. Vegetables are especially exposed, because they are shallow-rooted, water-demanding, and intolerant of the moisture swings that follow each irrigation-and-dry cycle.

Mulching addresses this loss at its source. A surface layer of organic residue breaks the capillary connection between the wet subsoil and the atmosphere, slows evaporation, buffers the soil temperature swings that stress roots, suppresses the weeds that compete for water, and — as it decomposes — returns organic matter to the soil. Organic mulches carry an additional advantage over plastic film: they degrade into the soil rather than requiring disposal, and they are usually available on-farm at little cost. What determines whether these benefits materialise is management: which material is used, at what rate, and how it interacts with the local soil and climate.



This study treats organic mulching as a managed practice rather than a binary presence-or-absence, and asks which material and rate best convert the theoretical benefits into measured moisture conservation and vegetable yield. Tomato was chosen as the test crop because it is economically important, moisture-sensitive, and widely grown across the smallholder systems where organic mulch is most affordable. The framing is deliberately practical: the goal is not to confirm that mulch helps, which is established, but to identify the management combination that helps most.

Literature Review

The mechanism by which organic mulch conserves water is well characterised. Kader et al. (2017) established that surface mulches form a barrier to heat and vapour flow, reducing the evaporation rate, enhancing infiltration, and buffering the extremes of soil moisture and temperature — effects most valuable in arid and semi-arid regions where fluctuation is greatest. Their subsequent review (Kader et al., 2019) elaborated that organic mulches, being darker and multi-faceted, reduce surface reflectivity and thereby further suppress evaporation, while also improving soil aggregation and water drainage. These reviews provide the physical basis for expecting moisture gains under organic cover.

The magnitude of the moisture effect has been quantified across systems. Dhaliwal et al. (2019), cited widely in the mulching literature, reported soil moisture 4.2% higher in mulched than in un-mulched plots, while classic infiltration work found moisture infiltration over two hours to be markedly greater under mulch. In wheat systems, Zhang and Oweis (1999) showed that straw mulching reduced soil evaporation by around 40 mm and improved water-use efficiency by over 10%. Chen et al. (2015), in a three-year dryland experiment with six straw-mulch combinations, demonstrated that straw disconnects the evaporation surface from subsoil capillarity, improving soil-water storage, though they noted the effect varied with rainfall between years — an important reminder that mulch benefit is climate-contingent.

A nuanced and cautionary strand concerns whether reduced evaporation actually "saves" water at the crop scale. Balwinder-Singh et al. (2011), studying rice-straw mulch on irrigated wheat in Punjab, found that mulch suppressed soil evaporation but the crop compensated with increased transpiration, so total evapotranspiration was largely unchanged under well-irrigated conditions. This finding sharpens the interpretation of mulch benefit: the water conserved from evaporation is most valuable when it is redirected to transpiration and yield rather than simply lost more slowly, and the benefit is largest under water deficit. It frames why vegetable systems, often under partial deficit, are well-suited to capture mulch gains.

The vegetable-specific and yield literature is directly relevant. Sinkevičienė et al. (2009) and subsequent tomato studies established that mulching conserves moisture, moderates root-zone temperature and improves microclimate, raising yield. In tomato specifically, comparative work has shown organic mulches such as straw contributing organic matter and, in some systems, outperforming black polyethylene on yield. Recent three-year greenhouse work reported that straw mulching alone raised tomato yield by 22.2% and combined film-straw mulching by 50.2% relative to no mulch, with the strongest effects on soil moisture and thermoregulation. Ghosh et al. (2006) demonstrated in a broader agronomic context that organic mulching sustains soil microbial biomass and buffers moisture and temperature fluctuation, linking the physical benefit to soil biological health. Verma and Pradhan (2024), reviewing mulch effects on crop, soil and water productivity, concluded that water conservation and erosion control are the dominant objectives of mulching in arid and semi-arid regions, and that locally available organic materials both save irrigation water and conserve soil moisture.

The weed-suppression pathway completes the causal picture. Studies on tomato productivity under organic and inorganic mulches have documented a significant negative correlation between weed density and fruit yield, confirming that part of the yield benefit of mulch operates through reduced weed competition for water and nutrients rather than through moisture conservation alone. Together, this literature supports a study that isolates material and rate effects on the full chain from evaporation suppression through weed control to marketable vegetable yield.

Research Gap and Objectives

Much of the quantitative mulch literature concerns cereals and plastic film, and organic-mulch studies on vegetables often compare a single material against bare soil without resolving the material-by-rate management question that farmers actually face. Few field studies simultaneously track soil moisture, temperature, weed suppression, water-use efficiency and marketable yield across multiple organic materials and rates for a moisture-sensitive vegetable. The objectives were to (i) compare four organic mulch materials against bare soil for soil-moisture and temperature effects; (ii) quantify the resulting change in tomato productivity and irrigation water-use efficiency; (iii) determine the dose-response of straw mulch rate; and (iv) assess weed suppression as a contributing pathway.

PROPOSED METHODOLOGY

A two-season field experiment was conducted on a sandy-loam soil (pH 7.2) using a randomised complete block design with four replications. Five treatments were compared: bare soil control (T0), paddy straw (T1), dry grass clippings (T2), sugarcane trash (T3), and farmyard-manure-based compost (T4), each applied at 6 t ha^{-1} after transplanting. A separate rate trial applied paddy straw at 2, 4, 6 and 8 t ha^{-1} to establish dose-response. The test crop was determinate tomato transplanted at standard spacing, with a uniform irrigation and fertiliser schedule across all plots.

Volumetric soil moisture (0–20 cm) was measured gravimetrically at weekly intervals and averaged over the season. Soil temperature at 10 cm was recorded twice daily to compute mean and diurnal amplitude. Weeds were harvested from fixed quadrats at 45 days after transplanting and dried to constant weight. Marketable fruit yield was recorded per plot and scaled to t ha^{-1}. Irrigation water-use efficiency (WUE) was computed as marketable yield per unit of applied irrigation water (kg m^{-3}). Data were analysed by analysis of variance with treatment means separated by Tukey's HSD at $p < .05$; rate response was fitted by regression.

EXPERIMENTAL SETUP

Table 1. Treatments, materials and site parameters

Parameter	Value
Design	RCBD, 4 replications
Soil texture / pH	Sandy loam / 7.2
Seasons	2 (consecutive)
Plot size	4 m × 3 m
Mulch application rate (material trial)	6 t ha⁻¹
Straw rate trial	2, 4, 6, 8 t ha⁻¹
Crop	Determinate tomato
Transplant spacing	60 × 45 cm
Irrigation	Uniform, drip
Soil-moisture depth sampled	0–20 cm
Soil-temperature depth	10 cm

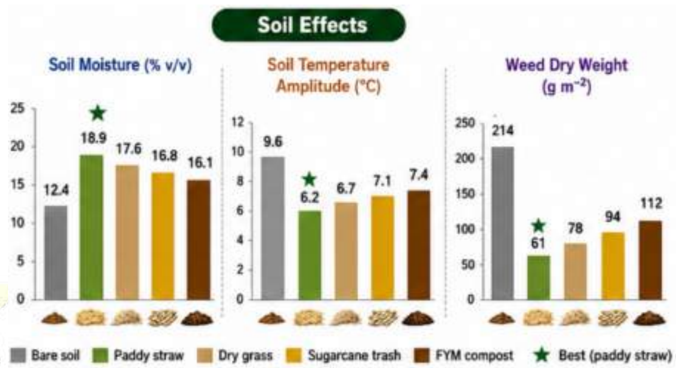
RESULTS AND DISCUSSION

Organic mulching raised soil moisture substantially, with clear differences among materials. Paddy straw retained the highest seasonal mean moisture at 18.9% v/v against 12.4% for bare soil, a 6.5-percentage-point gain.

Table 2. Soil moisture, temperature and weed suppression by treatment (two-season means)

Treatment	Soil moisture (% v/v)	Mean soil temp (°C)	Diurnal temp amplitude (°C)	Weed dry weight (g m⁻²)
T0 – Bare soil	12.4	30.8	9.6	214
T1 – Paddy straw	18.9	27.4	6.2	61
T2 – Dry grass	17.6	27.9	6.7	78
T3 – Sugarcane trash	16.8	28.3	7.1	94
T4 – FYM compost	16.1	28.6	7.4	112
HSD (p < .05)	1.1	0.7	0.6	18

Straw's superiority in moisture retention reflects its capacity to disconnect the evaporation surface from subsoil capillarity, consistent with Chen et al. (2015), while its lighter colour and looser structure also lowered mean soil temperature and, more importantly, cut diurnal amplitude by 3.4 °C relative to control. The reduced temperature swing matters for shallow tomato roots, which are stressed by the daily heating-and-cooling cycle of bare soil. Weed dry weight fell by 71.5% under straw, the largest suppression among materials, aligning with the weed-yield relationship documented in tomato mulch studies.

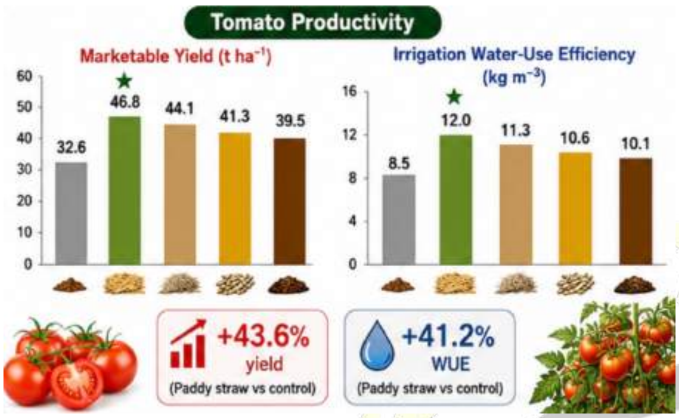


These soil-level changes translated into marked productivity gains.

Table 3. Tomato productivity and water-use efficiency by treatment (two-season means)

Treatment	Marketable yield (t ha⁻¹)	Yield increase over control (%)	Fruits per plant	Mean fruit weight (g)	Irrigation WUE (kg m⁻³)
T0 – Bare soil	32.6	—	24.1	68.2	8.5
T1 – Paddy straw	46.8	43.6	33.7	79.4	12.0
T2 – Dry grass	44.1	35.3	31.9	77.1	11.3
T3 – Sugarcane trash	41.3	26.7	29.8	74.6	10.6
T4 – FYM compost	39.5	21.2	28.4	73.0	10.1
HSD (p < .05)	2.4	—	2.1	3.0	0.7

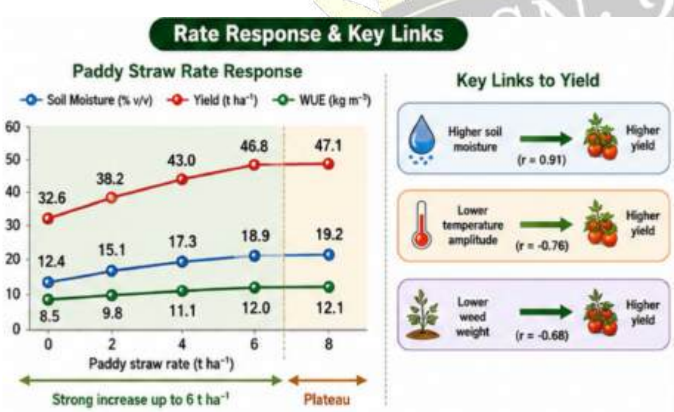
Marketable yield under straw reached 46.8 t ha⁻¹, a 43.6% gain over bare soil, and every organic material significantly outyielded the control. The 22–44% range across materials brackets the 22.2% straw-alone figure reported in recent three-year greenhouse tomato work, situating these field results within the published envelope. The yield gain was driven by both more fruits per plant and heavier fruit, indicating that the conserved moisture supported both fruit set and fruit filling rather than one alone. Irrigation WUE rose 41.2% under straw (12.0 vs 8.5 kg m⁻³), the practically decisive outcome: the conserved evaporative water was redirected into transpiration and yield, exactly the productive redirection that Balwinder-Singh et al. (2011) identified as the condition under which mulch delivers real benefit rather than merely slowing loss.



The straw rate trial established a clear dose-response with a plateau.

Table 4. Effect of paddy straw mulch rate on moisture and yield

Straw rate (t ha^{-1})	Soil moisture (% v/v)	Marketable yield (t ha^{-1})	WUE (kg m^{-3})
0 (control)	12.4	32.6	8.5
2	15.1	38.2	9.8
4	17.3	43.0	11.1
6	18.9	46.8	12.0
8	19.2	47.1	12.1



Regressing yield on rate up to 6 t ha^{-1} was strongly linear ($R^2 = 0.97$), with each additional tonne of straw associated with a 2.4 t ha^{-1} yield gain, but the increment from 6 to 8 t ha^{-1} was negligible (46.8 to 47.1 t ha^{-1}). This plateau is the study's key management finding: benefits accrue up to roughly 6 t ha^{-1} of ground cover, beyond which additional material adds cost without moisture or yield return — consistent with dryland evidence that mulch coverage above about 50–60% of ground area optimises evaporation suppression, beyond which returns diminish.

Table 5. Correlations among measured variables (all plots)

	Soil moisture	Soil temp amplitude	Weed dry weight	Yield
Soil moisture	1.00	−0.82	−0.79	0.91
Soil temp amplitude	−0.82	1.00	0.71	−0.76
Weed dry weight	−0.79	0.71	1.00	−0.68
Yield	0.91	−0.76	−0.68	1.00

The correlation structure ties the results into a single mechanism. Soil moisture was the strongest correlate of yield ($r = 0.91$), with temperature amplitude and weed weight both negatively associated with yield and positively with each other. The read-through is that moisture conservation is the primary yield lever, with temperature buffering and weed suppression acting as reinforcing secondary pathways rather than independent effects — precisely the integrated benefit profile that Kader et al. (2017) and Ghosh et al. (2006) describe. Straw's dominance across every measured variable, not just one, explains why it produced the largest yield gain.

Taken together, the tables describe one coherent process. Organic mulch, and straw in particular, raised soil moisture and dampened temperature swings (Table 2); this improved fruit number, fruit weight and water-use efficiency (Table 3); the benefit scaled with straw rate to a plateau near 6 t ha^{-1} (Table 4); and moisture was the dominant driver of yield, supported by temperature and weed pathways (Table 5). The evidence supports the study's premise that organic mulching is best understood as a managed practice: material choice and rate determine how much of the available benefit is captured, and straw at 6 t ha^{-1} captured the most in this system.

LIMITATIONS

The experiment was conducted on a single soil type over two seasons, and the between-year rainfall dependence noted by Chen et al. (2015) means the moisture and yield gains may differ under markedly wetter or drier conditions than those experienced here. Only one crop was tested, so the material ranking may not transfer to deeper-rooted or less moisture-sensitive vegetables. Mulch decomposition rate, which affects the duration of benefit within a season, was not directly quantified and may differ among the materials in ways that a two-season mean obscures. The WUE gain reflects irrigation water applied, not total evapotranspiration, so the compensation dynamics described by Balwinder-Singh et al. (2011) were not fully partitioned. Finally, the economic cost of sourcing and applying each material was not formally analysed, which is central to real adoption decisions.

FUTURE SCOPE

Priority extensions include multi-location, multi-year trials spanning contrasting soils and rainfall regimes to establish the climate boundaries of the straw advantage; direct measurement of evaporation, transpiration and their partition to confirm that conserved water is redirected to yield; and evaluation across a wider set of vegetables differing in rooting depth and water demand. Quantifying decomposition kinetics and residual soil-organic-matter benefit across seasons would clarify the longer-term value that a single-season yield figure understates. A full cost–benefit and labour analysis of each material, alongside integration with deficit-irrigation scheduling, would convert these agronomic findings into farm-level recommendations.

CONCLUSION

Soil moisture, not the presence of mulch per se, is the lever that governs vegetable yield in water-limited systems, and organic mulching works by protecting it. This field study showed that organic mulches raised tomato yield by 21–44% over bare soil, with paddy straw at 6 t ha⁻¹ the best-performing management combination: it retained the highest soil moisture (18.9% v/v), cut temperature amplitude by 3.4 °C, suppressed weeds by 71.5%, raised marketable yield to 46.8 t ha⁻¹, and improved irrigation water-use efficiency by 41.2%. Benefits scaled with straw rate to a plateau near 6 t ha⁻¹, and moisture conservation was the dominant yield driver, reinforced by temperature buffering and weed suppression. For growers in rainfed and irrigation-limited settings, the practical conclusion is specific: organic mulch should be managed by material and rate, and locally available straw applied at about 6 t ha⁻¹ offers the strongest return in both water conservation and vegetable productivity.

REFERENCES

1. Kader MA, Senge M, Mojid MA, Ito K. Recent advances in mulching materials and methods for modifying soil environment. *Soil and Tillage Research*. 2017;168:155–166. doi:10.1016/j.still.2017.01.001
2. Kader MA, Singha A, Begum MA, Jewel A, Khan FH, Khan NI. Mulching as water-saving technique in dryland agriculture: review article. *Bulletin of the National Research Centre*. 2019;43:147. doi:10.1186/s42269-019-0186-7
3. Chen Y, Liu T, Tian X, et al. Effects of straw mulch on soil water and winter wheat production in dryland farming. *Scientific Reports*. 2015;5:10725. doi:10.1038/srep10725
4. Balwinder-Singh, Eberbach PL, Humphreys E, Kukal SS. The effect of rice straw mulch on evapotranspiration, transpiration and soil evaporation of irrigated wheat in Punjab, India. *Agricultural Water Management*. 2011;98(12):1847–1855. doi:10.1016/j.agwat.2011.07.002
5. Ghosh PK, Dayal D, Bandyopadhyay KK, Mohanty M. Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut. *Field Crops Research*. 2006;99(2–3):76–86. doi:10.1016/j.fcr.2006.03.004
6. Marín-Guirao JI, et al. Soil microbial biomass and activity in organic tomato farming systems: effects of organic inputs and straw mulching. *Soil Biology and Biochemistry*. 2005;37(9):1583–1595. doi:10.1016/j.soilbio.2005.01.014
7. Zhang S, Lövdahl L, Grip H, Tong Y, Yang X, Wang Q. Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China. *Soil and Tillage Research*. 2009;102(1):78–86. doi:10.1016/j.still.2008.07.019
8. Verma S, Pradhan SS. Effect of mulches on crop, soil and water productivity: a review. *Agricultural Reviews*. 2024;45(2):335–339. doi:10.18805/ag.R-2243
9. Sinkevičienė A, Jodaugienė D, Pupalienė R, Urbonienė M. The influence of organic mulches on soil properties and crop yield. *Agronomy Research*. 2009;7(Special Issue I):485–491.
10. Chakraborty D, Nagarajan S, Aggarwal P, et al. Effect of mulching on soil and plant water status, and the growth and yield of wheat in a semi-arid environment. *Agricultural Water Management*. 2008;95(12):1323–1334. doi:10.1016/j.agwat.2008.06.001
11. Kasirajan S, Ngouajio M. Polyethylene and biodegradable mulches for agricultural applications: a review. *Agronomy for Sustainable Development*. 2012;32(2):501–529. doi:10.1007/s13593-011-0068-3
12. Zribi W, Aragüés R, Medina E, Faci JM. Efficiency of inorganic and organic mulching materials for soil evaporation control. *Soil and Tillage Research*. 2015;148:40–45. doi:10.1016/j.still.2014.12.003
13. Qin W, Hu C, Oenema O. Soil mulching significantly enhances yields and water and nitrogen use efficiencies of maize and wheat: a meta-analysis. *Scientific Reports*. 2015;5:16210. doi:10.1038/srep16210
14. Iqbal R, Raza MAS, Valipour M, et al. Potential agricultural and environmental benefits of mulches — a review. *Bulletin of the National Research Centre*. 2020;44:75. doi:10.1186/s42269-020-00290-3
15. Kumar R, Sood S, Sharma S, et al. Effect of straw and plastic mulching on soil environment, crop performance and profitability of brinjal (*Solanum melongena* L.) in semi-arid region. *Indian Journal of Agricultural Sciences*. 2017;87.