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Improved rainy season fallow management in vertisols for resource conservation

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Abstract
A two rainy season field experiments (2023-2024) were conducted at ICAR-Indian Institute of Millets Research, Hyderabad, India, to assess the utility of chemical fallow and dhaincha (*Sesbania aculeata*) green manuring on resource (soil moisture and nutrient) conservation as compared to traditional natural fallow. In this study, three fallow management treatments replicated eight times were evaluated in randomized complete block design setup. Results shows that chemical fallow and dhaincha green manuring have reduced the weed count (weed dry biomass) at 45 DAS by 76.5 (88.62) and 59.6% (76.5%) over natural fallow (23.4 weeds/m^2 and 422 kg ha^{-1}). On above reduced weed biomass, chemical fallow and dhiancha green manuring have reduced N, P and K uptake of weeds. Chemical fallow has 93.8, 93.2 and 90.6% lower weed nutrient removals has 10.9-19.4-8.3% higher available N-P-K nutrients than that in natural fallow (9.81-1.10-5.52 kg ha^{-1} N-P-K uptake and 181.2, 17.25 and 240.1 kg ha^{-1} N-P-K balance in soil). Though dhaincha green manuring (receiving 20-17.4-16.6 kg/ha N-P-K fertilizers) has lower weed nutrient removals, but huge nutrient accumulation in its dry biomass, hence it has a medium nutrient balance between chemical fallow and natural fallow. Chemical fallow has improved available soil moisture (mm/15 cm depth) by 26.5% over natural fallow (15.25 mm/15 cm), while dhinacha green manuring has 27.5% more water depletion over natural fallow. Dhaincha green manuring involves 4.4 times more costs than chemical fallow (Rs. 2400). Thus chemical fallow is both nutrient and water conservative practice to natural fallow while green manuring with biological N fixation is nutrient enriching practice.

Keywords: Natural fallow, chemical fallow, green manure, dhaincha, available soil moisture, weed count

Introduction
Vertisols, also known as black soils or black cotton soils are spread on 72-79 M ha that is 22% of its geographical area of India. They are primarily found in the Deccan Plateau and Central India, in the states of Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh and Telangana. These soils are characterized by high shrink-swell clays (montmorillonite), undergoing pronounced swelling when wet and cracking when dry, leading to self-mixing (argilli-pedo-turbation) and slicken sides (Kovda, 2020) [9]. Surface layers are slightly alkaline (pH :7.8-8.2) with $CaCO_3$ content increasing with depth (0.6-30%) and moderate salinity (EC: 0.3-0.4 dS m^{-1}). Such physical and chemical properties influence crop choice, nutrient dynamics, and fallow management strategies in rain fed agro-ecosystems. However, field operations must be carefully timed, as the soil is very sticky when wet and very hard when dry, limiting the workable period. Due to non-tillability of these soils in rainy season (June-September), they are left fallow that becomes ideal niche for growth of weeds and removal of precious water and nutrient resources into their biomass. This depletion of soil moisture and nutrients in vertisols often results in poor performance of succeeding *rabi* crops like sorghum, chickpea. In this context, appropriate fallow management becomes critical to sustain productivity. In this context, chemical fallow becomes useful in curtailing soil moisture and nutrient losses from weeds. Dhaincha (*Sesbania aculeata*) water-logging-tolerant green manure crop cultivation accumulates huge quantity of nitrogen through biological N fixation its biomass. Upon its incorporation, soil fertility get enriched, and water storage improves that ultimately results improved performance of the subsequent *rabi* season crops. In this context, utility of

chemical fallow and green manuring on weed biomass, nutrient and water use needs to be quantified as compared to traditional fallow, hence, the present study was conducted.

Materials and Methods

Field experiments were carried out for two consecutive *kharif* seasons of 2023 and 2024 at the GTC Farm of ICAR-Indian Institute of Millets Research (IIMR), Rajendra nagar, Hyderabad, Telangana state, India. The experimental site was situated at 17.19°N latitude and 78.23°E longitude at an elevation of 542 meters above mean sea level. As per Köppen-Geiger climate classification, it has a steppe climate (BSh). During the experimental period (July-August), a rainfall of 409.3 (15 rainy days) and 184.4 (19 rainy days) was received during 2023 and 2024 (Fig 1). The experimental clay loam soil was non-saline (EC: 0.15 dS m^{-1}) neutral (7.18 pH) was rated as low for organic carbon (0.38 and 0.41%), available nitrogen (198 and 206.4 kg ha^{-1}), medium for available phosphorus (18.0 and 20.0 kg ha^{-1}) and potassium (250.0 and 272 kg ha^{-1}). Field experiment with three treatments (dhaincha green manure, chemical fallow and natural fallow) replicated eight times was set up in randomized complete block design (RCBD). The experimental field for green manure crop was prepared by running a rotavator and Dhaincha (local variety) was broadcast sown using a seed rate of 40 kg ha^{-1} on 2nd July (27th meteorological week) and 27th June (26th meteorological week) during 2023 and 2024. A fertilizer dose of 20-17.4-16.6 kg ha^{-1} N-P-K was broadcast applied before ploughing that got incorporated with rotator running. Urea, single super phosphate, and muriate of potash were sources of fertilizer N, P and K. At flowering stage (~45 days after sowing), dhaincha biomass was incorporated (16 August 2023 and 12 August 2024) into the soil through rotavator. Soil samples were collected before sowing (initial) and immediately after incorporation of dhaincha biomass and were analyzed for available N, P and K by standard methods. In chemical fallow, post-emergence application of gluphosinate ammonium 13.5% SL @ 1 kg a.i./ha was done twice (17-07-2023 and 1-08-2023., 12-07-2024 and 29-07-2024). Weed attributes (weed count and dry weed biomass) were recorded at 45 DAS coinciding with dhaincha incorporation. Nutrient (N, P and K) concentration (%) in weeds was estimated as per standard procedures and nutrient uptake (kg/ha) was arrived at by multiplying nutrient concentration with weed dry matter (kg ha^{-1})/100. Soil moisture content was determined gravimetrically from field-collected samples at incorporation stage of dhaincha from 0-15 cm depth. Immediately after sampling, the moist weight of each sample was recorded, and the samples were oven-dried at 105 ± 2 °C to a constant weight (24 hours). Available soil moisture was then estimated by subtracting the moisture content in dry soil from the moist sample and multiplying it with bulk density and depth. Data were subjected to statistical analysis as per the procedures outlined by Gomez and Gomez (1984) [5]. Treatment means were compared using the critical difference (CD) at 5% level of significance.

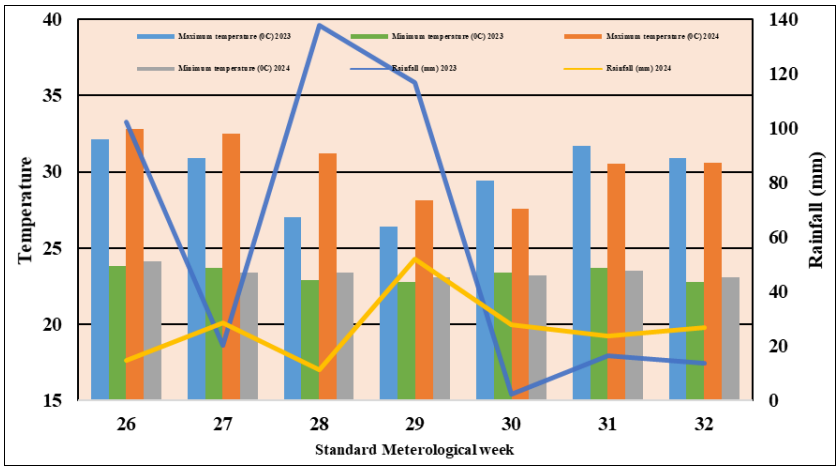

Fig 1: Weekly weather data during fallow management period of two years.

Results and Discussion

The results of the two-year field experiments were presented here and are discussed in cause and effect relationship and were compared with the earlier findings.

Influence of fallow management on weed count and weed biomass

Data on weed attributes at 45 DAS as influenced by fallow management treatments were presented in Table 1. Data shows that chemical fallow has recorded significantly lower weed count and biomass (dry) than natural fallow during both the years of study. The weed count (number/m^2) at green manure incorporation stage (45 DAS) ranged from 4.1-26.5. Natural fallow has recorded 2.47 and 4.25 times more weed count than that in dhaincha green manure crop and chemical fallow. Mean dry weed biomass ranged from 48-422 kg ha^{-1} with chemical fallow having recorded least biomass that was 88.62% lower than that with natural fallow (422 kg/ha). Weed biomass reductions were greater than weed count in green manure plots (1.28 times) while chemical fallow has 1.15 ratio between weed biomass and weed count reduction.

The reduction in weed count and weed biomass in chemical fallow is attributed complete kill of standing weeds through two times spray of glufosinate ammonium, a non-selective herbicide that inhibits the enzyme glutamine synthetase, leading to rapid accumulation of ammonia in plant tissues and subsequent cell death. In Dhaincha green manure plots, rapid germination and quick canopy cover build up and its closure has resulted in suppressed weed count and weed dry weight. Our results of chemical fallow were supported by findings of Dhanda and Kumar (2025) [4] who reported 82 to 97% reduction weed density, and up to 95% reduction in weed dry biomass when compared to weedy fallow. Similar impacts of chemical fallow weed growth were reported by Torbiak *et al.* (2020) [18] when compared to weedy fallow. Our results of dhaincha green manure crop on weed density were corroborated with findings of Gurudivya *et al.* (2025) [7] who reported 7 times lower weed density with dhaincha crop as compared to fallow (56/m^2).

Table 1: Impact of fallow management practices on weed count and weed dry biomass production during 2023 and 2024

Fallow Management	Weed count (m^2)		Dry weed biomass (kg ha^{-1})	
	2023	2024	2023	2024
Natural Fallow	20.3	26.5	459	395
Chemical fallow	4.1	6.9	54	42
Dhaincha	8.3	10.6	103	95
Mean	10.9	14.7	205.3	177.3
S.Em±	0.5	0.4	0.5	0.7
CD (p = 0.05)	1.5	1.1	1.4	2.0
CV (%)	13.37	7.15	6.72	10.83

Available soil moisture and nutrient uptake by weeds and fallow management

Data pertaining to available soil moisture (ASM) content in 0-15 cm top soil and nutrient uptake by weeds at 45 DAS during both the years of study are given in Table 2. Nutrient concentration in weed biomass (mean of all weeds) was given in Fig:2. Data shows that chemical fallow has significantly higher ASM during both the years of study while natural fallow has the lowest ASM values. On mean basis, chemical fallow recorded 50.16% higher ASM than natural fallow (15.25 mm/ 15 cm depth). Dhaincha green manuring has an ASM that is 27.5% lower than natural fallow. Higher ASM in chemical fallow plots could be attributed to the near exclusion of weeds and associated water transpiration losses curtailment (evaporation could be higher, in directly measured through ASM). High ASM in chemical fallow reported in our study over natural fallow were corroborated by the findings of Manalil and Flower (2014) [11] who reported 11.1% higher ASM in 1.5 m depth of soil than weedy fallow.

Nutrient (NPK) uptake by weeds in chemical fallow treatment was significantly lower than that in dhaincha green manure plots and natural fallow during both the years of study. Natural fallow has significantly higher weed nutrient uptake among three fallow management treatments (Table 2). The mean N uptake by weeds under natural fallow (9.81 kg ha^{-1}) was 16.08 and 4.79 times higher than that with chemical fallow (0.61 kg ha^{-1}) and dhaincha green manuring (2.04 kg ha^{-1}). The mean P uptake by weeds in natural fallow (1.10 kg ha^{-1}) was 5.00 and 15.7 times higher than that after dhaincha green manuring (0.22 kg ha^{-1}) and chemical fallow (0.07 kg ha^{-1}). Similarly, mean K uptake by weeds in natural fallow (5.52 kg ha^{-1}) was 4.75 and 10.62 times higher than that after dhaincha green manuring (1.16 kg ha^{-1}) and chemical fallow (0.52 kg ha^{-1}). Higher N, P and K uptake by weeds in natural fallow could be ascribed due to higher weed dry biomass production. In proportion of weed biomass reduction, chemical fallow plots have recorded the least nutrient uptake by weeds. Dhaincha green manure plots too have curtailed nutrient uptake by weeds which could ascribed to rapid canopy growth that smothered and shaded the weed growth. Reduced space for weeds by germinating dhaincha might have contributed to the hindered weed germination, emergence and growth. Our findings with green manuring align with that of Chauhan *et al.* (2012) [3] and Teasdale et al. (2007) [17] who demonstrated that shading and smothering by green manure and cover crops significantly suppress weed growth and nutrient extraction. Our higher N uptakes by weeds in natural fallow than chemical fallow were supported by the findings of Bahadur *et al.* (2022) [1] who reported a 65-80% reduction in weed N uptake under green manure crop compared to bare fallow. Similarly, our results on P uptake are corroborated by the findings of Sinchana *et al.* (2020) [16] who reported 14.1% higher P uptake by weeds in natural fallow when compared to chemical fallow. Kusumavathi *et al.* (2018) [10] also reported that Dhaincha as green manure significantly reduces weed P uptake from 1.1 (fallow) to 0.26 kg ha^{-1}

Table 2: Impact of fallow management treatments on available soil moisture and nutrient uptake by weeds (kg ha^{-1})

Treatment	Available soil moisture (mm/15 cm)		N uptake		P uptake		K uptake	
	2023	2024	2023	2024	2023	2024	2023	2024
Natural fallow	15.8	14.7	8.97	10.65	0.99	1.22	5.40	5.64
Chemical fallow	23.9	21.9	0.61	0.80	0.06	0.09	0.51	0.52
Dhaincha	11.2	10.9	1.93	2.16	0.21	0.24	1.11	1.20
Mean	17.9	19.6	3.84	4.54	0.42	0.52	2.34	2.45
S.Em±	0.30	1.23	0.20	0.169	0.025	0.023	0.129	0.066
CD (p = 0.05)	0.90	3.72	0.61	0.51	0.08	0.07	0.39	0.20
CV (%)	4.70	17.74	14.77	10.57	16.83	12.41	15.63	7.56

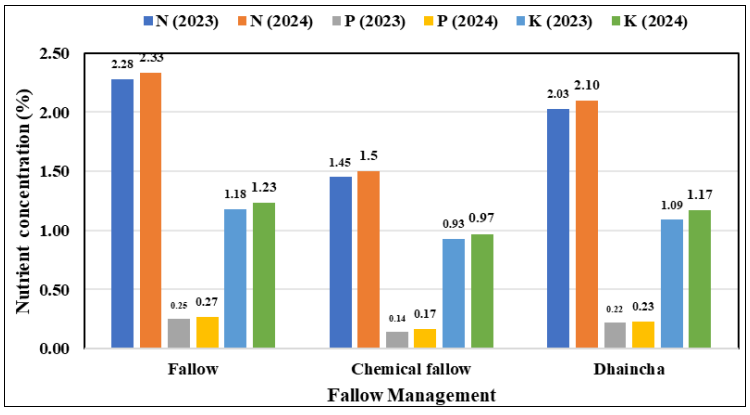

Fig 2: Nutrient concentration of weeds and fallow management

Biomass production, nutrient content and uptake by dhaincha green manure

Nutrient concentration (N, P and K) and uptake by dhaincha green manure crop from its above ground biomass at the time of incorporation (45 DAS) was given in Table 3. Data shows that dhaincha has a mean fresh and dry biomass production of 17.29 and 5.4 t ha^{-1}. Both fresh and dry biomass production by Dhaincha was 9% higher in 2024 than 2023. The above biomass on mean basis containing 2.51-0.415-1.39% N-P-K accumulated 135.5-22.3-74.9 kg ha^{-1} N-P-K nutrients. Our dry biomass production from dhaincha were similar to that of Irin *et al.* (2017) [8] Sharma and Behera (2009) [14] who obtained a dry matter production of 5.12 and 4.75 t ha^{-1}. Nutrient richness of dhaincha biomass reported in our study are supported by Najan *et al.* (2023) [13] who reported 3.90-0.43-2.10% N-P-K in Dhiancha biomass (N and K values were quiet higher than ours).

Table 3: Biomass production, nutrient concentration and uptake by dhaincha green manure crop

Dhaincha	2023	2024	Mean
N Concentration (%)	2.47	2.54	2.51
N uptake (kg ha^{-1})	127.7	143.3	135.5
P Concentration (%)	0.38	0.45	0.415
P uptake (kg ha^{-1})	19.41	25.10	22.26
K Concentration (%)	1.36	1.42	1.39
K uptake (kg ha^{-1})	69.7	80.0	74.9
Fresh Biomass (t ha^{-1})	16.54	18.05	17.30
Dry Biomass (t ha^{-1})	5.177	5.64	5.41

Soil nutrient status and Soil nutrient balance

Data pertaining to soil nutrient availability status at 45 DAS and nutrient balance is given in Table 4. Soil nutrient availability data indicates that chemical fallow closely followed by dhaincha green manure treatments have recorded significantly higher available N, P and K nutrients during both the years than natural fallow. On a mean basis, available N in soil under chemical fallow (201.1kg ha^{-1}) was 3.7 and 10.9% higher than that under (193.8 kg ha^{-1}) and under natural fallow (181.2 kg ha^{-1}). Chemical fallow plots mean available P (20.6 kg ha^{-1}) was 6.4 and 19.4% higher than dhaincha (19.35 kg ha^{-1}) and natural fallow (17.25 kg ha^{-1}). Likewise, mean available K in chemical fallow (259.9 kg ha^{-1}) was 2.4 and 8.2% higher than under dhaincha (253.8 kg ha^{-1}) and natural fallow (240.1 kg ha^{-1}). In general, available N, P and K during 2024 was 3.4, 10.9 and 9.0% higher than that during 2023. In chemical fallow, weeds were efficiently controlled that reduced the nutrients uptake by weeds than natural fallow. Dhaincha cultivation however, has resulted in reduction in available N, P and K in the soil due to fact that the crop has accumulated these nutrients in its biomass. Our nutrient depletion results with dhaincha green manuring were supported by the findings of Venkata Dathamma *et al.* (2024) [19] who reported 25.2-8.0-33.3% lower available N-P-K than its initial level. Our higher P values under chemical fallow over natural fallow were supported by findings of Gu *et al.* (2019) [6], who observed 10.2% higher available P in chemical fallow than natural fallow.

Data pertaining to nutrient balance in the soil at 45 DAS indicates that On mean basis, dhaincha green manured plots registered a net gain in nutrients (109.0-5.4-52.2 kg ha^{-1} N-P-K) while natural fallow has recorded a net loss (−11.3-0.7-15.3 kg ha^{-1} N-P-K). Chemical fallow has slight positive balance of P (1.7 kg ha^{-1}) but a loss of N and K (0.55 and 0.54 kg ha^{-1}). The higher N and P in dhaincha green manure plots was attributed to biological N_2 fixation and mobilization of fixed P from deeper soil layers through solubilization by the roots and associated P mobilizing organisms. Positive N balance reported in our study are in line with the findings of Beri *et al.* (2001) [2] and Sharma & Ghosh (2000) [15]. Similarly, P and K positive balances of our study were corroborated by the findings of Mangaraj *et al.* (2022) [12] who reported that dhaincha green manuring has net positive balance of P and K (8.9 and 26.9 kg ha-1). Natural fallow loss of nutrients is ascribed to their removal by weeds that was curtailed in chemical fallow and thus has almost status quo for nutrients.

Table 4: Nutrient balance sheet (kg/ha) under different fallow management practices at 45 days after sowing (dhaincha incorporation stage) during *kharif* 2023 and 2024

Treatment	Initial N-P-K (a)	N-P-K applied (b)	N-P-K uptake: weeds + crop (c)	Soil N-P-K status at 45 DAS (d)	Apparent balance (a+b)-c= e	Net loss /gain (d-e)
2023						
Natural Fallow	198.3-18-250	-	8.97-0.99-5.40	178.8-15.9-230.3	189.3-17.0-244.6	-10.5[1]-1.1[1]-14.3[1]
Chemical Fallow	198.3-18-250	-	0.61-0.06-0.51	197.0-19.9-248.0	197.7-17.9-249.5	-0.7[1]-2.0[1]-1.5[1]
Dhaincha*	198.3-18-250	20-17.46-16.6	129.6-19.6-70.8	190.5-18.7-243.1	88.7-15.8-195.8	101.8-2.9[1]-47.3
CD 5%				6.74-1.21-14.57		
2024						
Natural Fallow	206.4-20-272	-	10.7-1.2-5.6	195.7-18.6-250.0	195.8-18.8-266.4	-0.1[1]-0.2[1]-16.4[1]
Chemical Fallow	206.4-20-272	-	0.80-0.1-0.5	205.2-21.3-271.9	205.6-19.9-271.5	-0.4[1]-1.4-0.4
Dhaincha*	206.4-20-272	20-17.46-16.6	145.5-25.3-81.2	197.1-20.0-264.5	80.9-12.1-207.4	116.2-7.9-57.1
CD 5%				8.76-2.11-13.35		

* nutrient uptake in dhaincha crop and weeds; [1] negative balance (loss)

Fallow management costs

Data pertaining to fallow management costs during both the years of study is depicted in Fig 3. Figure shows that fallow management through dhaincha green mnauring on mean basis involves an additional expenditure of Rs.10,567 ha^{-1} that is 4.40 times higher than that with chemical fallow (Rs. 2400). Thus natural fallow appears as the most cost-effective option (no expenses). Higher expenditures involved in dhaincha green manuring were ascribed to cultivation costs (rotavator operation, seed cost, sowing and fertilizers costs) and incorporation costs too (not included in this calculation, would be further higher if added). In contrast, chemical fallow required only herbicide + labour application charges.

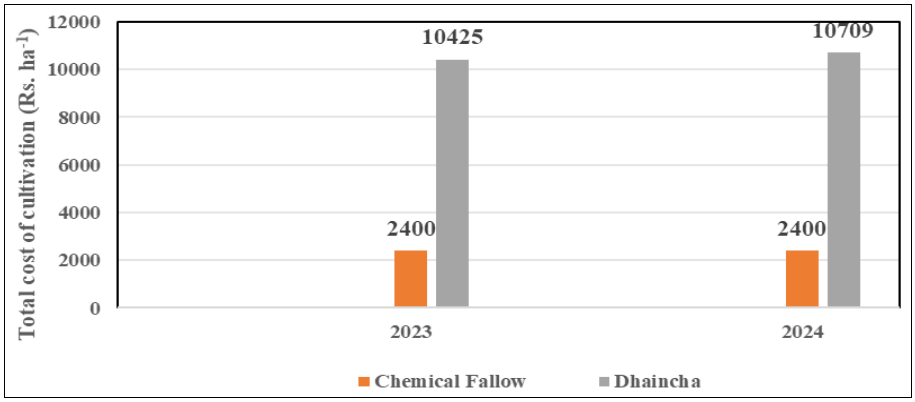

Fig 3: Additional costs of fallow management.

Conclusion

From the two-year study, it is concluded that chemical fallow (through two times spraying of glufosinate ammonium herbicide) is cost effective resource conserving (especially water) rainy season fallow management for *vertisols* when compared to natural fallow. Though dhaincha green manuring is a costly fallow management proposition apparently, when soil nutrient enrichments benefits (subsequent crop performance) are accounted, it will be obviously becomes the best fallow management practice. However, Dhaincha crop is utilizing the precious water resource for biomass production and if rains received succeeding to green manure crop incorporation are low, the crop is likely to have low yields especially in shallow vertisols. However, for deep vertisols, dhaincha green manuring is best fallow management option.

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