Effects of cow-based preparations and mulching on weed management and nodulation in chickpea under intercropping system

Abstract

Mulching is one of agronomic practices with goals of lowering soil evaporation, preserving moisture, regulating soil temperature, inhibiting weed development, and enhancing microbial activity. It is mostly predicated on the recycling of biomass within the farm, with a focus on biomass mulching, the use of cow dung and urine preparations within the farm and preserving soil aeration. A field experiment was conducted for two years during the spring season (2019-20 and 2020-21) at Palampur, Himachal Pradesh (India), which comprises different combination of g*hanjeevamrit* (mixture of urine, dung, jaggery and chickpea flour), *jeevamrit* (mixture of urine, dung, jaggery, chickpea flour, handful soil, and water) and mulching (added at rate of 10 t ha^{-1}). The weed count, weed dry matter, and yield of wheat as well as chickpeas were studied under sub-temperate humid zone (India). Data showed that application of cow-based preparations *(ghanjeevamrit-* added at rate of 0.5 t ha^{-1}, *jeevamrit*-1st spray at rate 5%, 2nd spray 7.5% and subsequent sprays 10% *jeevamrit* in the water with the rate of 200 L $acre^{-1}$ at 21 days interval) and mulching significantly affected weed count, dry matter, weed control efficiency and number of nodules of chickpea. Based on data of both years significantly lower weed count and dry weight at 120 DAS (before that weed count and dry weight was not affected significantly) was recorded in treatment T7*(ghanjeevamrit + jeevamrit + mulching)* which was statistically at par with T3 (mulching), T5 (*ghanjeevamrit* + mulching), T6 (*jeevamrit* + *mulching*) and T8 (control). At 150 DAS, significantly lower weed count was recorded in T5 which was at par with T3 and T6 and a significantly highest count was recorded in T4 (ghanjeevamrit + *jeevamrit*). At harvest, the highest weed count and dry weight of weed were found in treatment T2 (*jeevamrit*), T4, T1 (*ghanjeevamrit*), and T8. Similarly, the weed control efficiency was recorded numerically highest under T7 treatment. Minimum weed count and weed dry weight were found in the T7 treatment. Significantly highest nodule count in chickpea was recorded in T7 followed by T4*,* whereas the lowest was recorded in T8. Therefore, this study highlights the combined use of cow-based preparations with mulching to decrease weed count, dry matter as well as the number of nodules of chickpea increases under natural farming.

Keywords: cow-based preparations, dry matter, *ghanjeevamrit*, *jeevamrit,* mulching, nodule, weed count, weed control efficiency

Introduction

Mulching is a widely recognized practice in sustainable agriculture that involves covering the soil surface with organic or inorganic materials to achieve multiple benefits, one of the most significant being weed control. Intercropping involves the strategic planting of two or more crops on the same piece of land, maximizing productivity and enhancing soil health is as a sustainable agricultural practice, holds immense promise for improving crop productivity, particularly in the context of natural farming systems (Ikeh *et al*, 2012). Integrating of multiple crops in a single field offers numerous ecological benefits, including efficient resource utilization, weed suppression, pest management, and improved soil fertility. In recent years, the focus on natural and organic farming methods has gained considerable traction due to their emphasis on ecological balance, reduced chemical inputs, and the promotion of soil health. In the context of sustainability, organic inputs are essential alternative to chemical farming (Sharma *et al*., 2024; Sharma *et al*., 2023). Organic inputs focuses on sustaining soil health by utilizing on-farm organic wastes, beneficial microbes, intercrops and legumes in cropping sequences (Kumar *et al*., 2022; Narwal *et al*., 2024) Central to these practices is the use of organic fertilizers and bio-inoculants, such as *ghanjeevamrit, jeevamrit*, and *beejamrit*, which are derived from natural sources and are known to enhance soil microbial activity, nutrient availability, and plant growth (Choudhary *et al.,* 2022). When combined with mulching, another cornerstone of natural farming, these organic inputs create a synergistic effect that supports the establishment of a thriving agroecosystem. Intercropping systems, such as wheat and chickpea, can benefit from the application of organic fertilizer formulations like *ghnjeevamrit*, *jeevamrit,* and *beejamrit*, especially when combined with mulching practices. Research has shown that intercropping can lead to overyielding due to mechanisms like rhizosphere phosphorus facilitation, which enhances agricultural productivity (Li *et al.,* 2007; Ikeh *et al,* 2023a). Additionally, the use of biofertilizers and mulching has been found to positively impact yield and yield components of crops like purslane (Rohi-Saralan *et al.,* 2018). Furthermore, the application of bio-fertilizers without nitrogen has been shown to increase grain yield in intercropping systems (Veisi, 2020). In addition, Ikeh *et al.* (2023b) reported significant improvement in foliar yield of waterleaf (*Talinum triangulare* Jacq) with application of cow dung extract in an ultisol of southeastern Nigeria.

In intercropping systems, the choice of legume species and appropriate management practices, such as relay intercropping with subsidiary legumes, can support weed management and optimize nutrient cycling (Leoni *et al*., 2022; Naik et al., 2024). Moreover, the inoculation of rhizobacterial consortia has been found to alleviate combined water and phosphorus deficit stress in intercropped faba bean and wheat, improving phosphorus solubilization and P nutrition under stressful conditions (Cheto *et al*., 2023).

Mulching, both with straw and plastic, has been highlighted as a beneficial practice in intercropping systems. It can enhance crop productivity by optimizing interspecific interactions, increasing organic matter content, conserving soil moisture, and improving microenvironments for better water utilization as well as adding nutrients in the soil (Yin *et al.,* 2019; Yin *et al*., 2019; Ikeh *et al*, 2019). Additionally, the use of organic mulch has been associated with improved soil physical and chemical properties, root activity, and nutrient status, ultimately impacting crop yield and quality (Zhang *et al*., 2020).

Effective weed management is also critical for optimizing crop yield, as weeds compete with crops for resources and can significantly reduce productivity. Therefore, this study aims to investigate the impact of organic fertilizer formulations, specifically *ghanjeevamrit, jeevamrit*, and *beejamrit*, in conjunction with mulching, on root nodule formation, weed suppression, and the overall yield of wheat and chickpea intercropping systems under the framework of natural farming.

Material and Methods

The field experiment was conducted during rabi season for two consecutive years 2019-20 and 2020-21 at ZBNF farm (located at 32°09´ N latitude, 76°5´ E longitude and 1224 meters above mean sea level), Holta, Palampur, Himachal Pradesh, India. The place falls in the sub-temperate, mid-hills of North-West Himalayas in the Palam Valley of Kangra district. Total rainfall of 718.90 mm and 364.8 mm was received during the cropping season 2019-20 and 2020-21, respectively. oil samples were collected randomly from 0-15 cm depth on the site using soil auger, mixed thoroughly, bulked, air dried and sieved to pass through a 2 mm sieve for chemical analysis. The soil of experimental field was silty clay loam in texture with sand- 21.3%, silt- 42.4% and clay- 34.6% (Piper 1966); pH (1 : 2.5, soil : water)- 5.08, electrical conductivity (EC 1 : 2, soil : water)- 0.096 dS m^{-1} (Jackson, 1967); organic carbon- 0.77 % (Walkley and Black, 1934); available N- 256 kg ha^{-1} (Subbiah and Asija, 1956), available P- 15.9 kg ha^{-1} (Olsen *et al*., 1954) and available K- 277 kg ha^{-1} (AOAC, 1970). The experiment was laid out in randomized block design comprising of 3 replications and eight treatments i.e., T1-ghanjeevamrit @ 5 q ha^{-1} before sowing, T2 – jeevamrit (foliar application at 21 days interval), T3 - mulching @10 t ha^{-1}, T4 - ghanjeevamrit + jeevamrit, T5-ghanjeevamrit + mulching, T6 - jeevamrit + mulching, T7 - ghanjeevamrit + jeevamrit + mulching, T8 - control. Wheat was intercropped with chick pea crop under HPW 368 and Him channa 2 variety, respectively. For the calculation of dry weight and weed population, an iron square of size 30 cm was used to make observations through random sampling in each plot at 30, 90, 60,120 DAS. The total number of weeds was counted species-wise from each plot separately and analyzed after observing the original data to square root transformation ($\sqrt{x+1}$). Five plants were chosen at random from each plot for nodule counting at the flowering stage. The average number of nodules per plant was counted after the soil adhering to the root system was carefully removed by washing with tap water.

Similarly, for the dry weight of weeds, weeds were collected from each plot in 25cm quadrate and then the fresh weight of the samples after put into the oven at 70 degrees Celsius temperature for 72 hours, weighed (g m^{-2}.). The weed control efficiency was determined as described by Shehata et al. 2019.

Weed control efficiency (%) = (WDWC−WDWT)/(WDWC) × 100

where WDWC = weed dry weight in the unweeded check; WDWT = weed dry weight in treatment.

Result and Discussions

Weed count

The field was monitored during different crop growth phases at monthly intervals and weed count was taken during both the cropping years (2019-20 and 2020-21). On an average, total 12 weed species were found growing in association with crops during both the years. The perusal of data presented in Table 1 revealed that during both the years, the total weed count was maximum at 120 days after sowing (DAS) in the experimental field. The major weed spp. found in maximum number were *Phalaris minor*, *Lolium temulentum*, *Anagallis arvensis*, *Vicia spp*., *Poa anua*, *Spergulla arvensis* and *Coronopus didymus* etc. Weed count was significantly affected at 120, 150 DAS and at harvest during 2019-20, whereas in the rest of the observation stages it was not significantly affected. At 120 DAS significantly lower weed count was recorded in treatment T7 which was statistically at par with T3, T5 and T6. At 150 DAS, a significantly lower weed count was recorded in T5 which was at par with T3 and T6 and significantly highest count was recorded in T8. At harvest, the significantly least weed count was recorded in T7 which was at par with T3 and T5, whereas the highest weed count was recorded in T8. The lowest weed count was recorded in treatments where mulching was a component of treatment and this might be due to the suppressing effect of mulching on weeds.

Ranjit and Suwanketnikom (2003) also found similar result in an experiment conducted Khumaltar (Nepal) to studied the response of weeds and wheat yield to tillage and weed management. They revealed that straw mulch reduced narrow leaf weeds up to 23 per cent and broadleaf weeds up to 36 per cent compared to unweeded at 4 weeks after the sowing of wheat.

Weed dry weight

A perusal of two years' data presented in Table 2 revealed that in 2020-21, total dry weed weight at 120 days after sowing was higher in comparison to other growth stages. The weed dry weight was increased with the advancement of the weed count, despite treatments. The weed dry weight followed a similar trend as weed count and was maximum in T8 (control). The lowest total weed dry weight was found in treatments where mulching was applied as treatment or part of treatment *i.e., ghanjeevamrit* + *jeevamrit* + mulching (T7). The combined use of these suppress dry weight of weeds as mulching creates a physical barrier, limiting sunlight for weed germination while *ghanjeevamrit* and *jeevamrit* promote crop vigor, outcompeting weeds for resources (Mechergui *et al.,* 2021).

Weed control efficiency

Weed Control Efficiency (WCE) is the ability to manage weeds effectively, minimizing their presence and competition with crops for resources (Berquer et al., 2023). Data presented in Table 3 revealed that highest WCE was observed with the application of *Ghanjeevamrit* + *jeevamrit* + mulching (T7) whereas lowest WCE was observed in control treatment (T8). Mulching suppresses weed growth by blocking sunlight, which inhibit weed seed germination and photosynthesis. Additionally, mulching maintains soils moisture and temperature, creating unfavorable conditions for weed proliferation while *jeevamrit* promoting vigorous crop development, enhancing weed control efficiency in crop plants (El-Beltagi *et al.,* 2022).

Number of root nodules per plant at 50 % flowering

The data from both the years on the effect of different treatments on the number of nodules per plant at 50% flowering stage have been given in Table 4. The number of nodules per plant was significantly influenced by different treatments. Application of *ghanjeevamrit* + *jeevamrit* + mulching (T7) and *ghanjeevamrit*+ mulching (T5) recorded significantly highest number of nodules per plant in pooled (27.8 and 26.6 respectively). The treatments T5, T4 (*ghanjeevamrit* + *jeevamrit),* T6 (*jeevamrit* + mulching) and T2 (*jeevamrit*) were at par with each other. The significantly lowest number (21.8) of nodules were recorded in T8 (control). The higher number of nodules in T7 might be due to an increase in microbial activity in the soil as a result of the combined application of *ghanjeevamrit*, *jeevamrit* and mulching.

Similar results were also observed by Sreenivasa et al. (2009) while studying effect of *beejamrit* on plant growth, although Ikeh *et al*. (2023c), reported significant variations root nodulation and yield of cowpea cultivars in Nigeria which was attributed to inherent characteristics of different genotypes and subject to the prevailing environment condition of rainfall ecology of southeastern Nigeria.

Conclusion

The study underscores the importance of integrated approaches to weed management and soil health, particularly the combination of organic treatments (like *ghanjeevamrit* and *jeevamrit*) with mulching. These practices not only reduce weed competition but also improve soil microbial activity, leading to better plant growth and higher nodule formation. Therefore, using organic treatments and mulching together can be a sustainable strategy to enhance crop productivity while managing weeds effectively.

Table 1. Effect of different components of natural farming on weed count m^{-2} in wheat+ gram cropping system

Treatment		Total weed count m^{-2}									
		60 DAS		90 DAS		120 DAS		150 DAS		At Harvest	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
T1	*Ghanjeevamrit* @ 5 q ha^{-1} before sowing	5.4 (29.6)	7.6 (57.0)	7.4 (55.56)	8.5 (71.9)	7.7 (59.2)	10.4 (107.7)	7.2 (51.8)	9.1 (83.0)	6.9 (48.1)	8.7 (75.3)
T2	*Jeevamrit* (foliar application at 21 days interval)	5.7 (33.3)	8.0 (64.4)	7.9 (63.0)	8.7 (75.6)	8.1 (66.7)	10.7 (114.1)	7.6 (59.2)	8.9 (79.3)	7.4 (55.5)	8.5 (71.9)
T3	Mulching @ 10 t ha^{-1}	4.3 (18.5)	7.0 (49.6)	6.4 (40.7)	7.5 (56.1)	6.7 (44.8)	9.6 (91.9)	6.1 (37.0)	8.0 (64.4)	5.7 (33.3)	7.8 (60.7)
T4	*Ghanjeevamrit* + *jeevamrit*	6.3 (40.7)	8.0 (64.4)	8.1 (66.6)	8.5 (71.9)	8.6 (74.1)	10.5 (110.4)	7.8 (62.1)	9.1 (83.0)	7.6 (59.2)	8.7 (75.6)
T5	*Ghanjeevamrit* + mulching	4.6 (22.2)	7.2 (51.3)	6.1 (37.0)	7.1 (49.6)	6.4 (40.7)	9.2 (84.4)	5.4 (29.6)	7.6 (57.0)	5.5 (30.6)	7.3 (54.3)
T6	*Jeevamrit* +mulching	5.1 (25.90	7.0 (49.0)	6.4 (40.7)	7.6 (57.9)	6.6 (44.4)	9.6 (91.9)	6.1 (37.0)	7.8 (60.7)	5.7 (33.3)	7.3 (53.3)
T7	*Ghanjeevamrit* + *jeevamrit* + mulching	4.6 (22.2)	6.8 (45.9)	6.0 (37.0)	7.3 (52.4)	6.3 (40.7)	9.2 (84.4)	5.7 (33.3)	7.5 (57.0)	5.4 (29.6)	7.1 (49.6)
T8	Control	6.0 (37.03)	9.1 (74.4)	8.9 (70.8)	9.7 (85.2)	9.3 (77.2)	10.9 (116.7)	8.2 (67.9)	9.7 (90.9)	8.1 (65.6)	9.3 (77.6)
SEm±		**0.5**	**0.3**	**0.4**	**0.2**	**0.4**	**0.4**	**0.3**	**0.4**	**0.3**	**0.4**
CD (P=0.05)		**NS**	**NS**	**NS**	**NS**	**1.26**	**NS**	**1.09**	**NS**	**1.03**	**NS**

The data given in the parentheses are the means of original values

Table 2. Effect of different components of natural farming on weed dry weight m^{-2} in wheat+ gram cropping system

Treatment		Total dry weight (g m^{-2})									
		60 DAS		90 DAS		120 DAS		150 DAS		At Harvest	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
T1	*Ghanjeevamrit* @ 5 q ha^{-1} before sowing	11.94	13.65	21.56	28.06	32.85	40.40	27.80	35.19	25.07	30.29
T2	*Jeevamrit* (foliar application at 21 days interval)	13.75	16.23	23.64	28.62	35.92	43.50	29.22	33.03	21.78	28.43
T3	Mulching @ 10 t ha^{-1}	9.67	11.08	18.10	23.36	27.75	32.08	21.34	25.86	18.45	23.35
T4	*Ghanjeevamrit* + *jeevamrit*	15.11	16.34	22.62	26.61	36.25	42.68	28.75	35.55	25.44	30.24
T5	*Ghanjeevamrit* + mulching	9.56	12.26	16.00	21.47	24.15	27.97	18.21	22.53	15.19	19.79
T6	*Jeevamrit* +mulching	10.02	10.97	15.95	19.87	26.78	32.88	19.46	24.11	17.50	19.76
T7	*Ghanjeevamrit* + *jeevamrit* + mulching	8.94	9.66	14.05	19.80	21.94	27.83	17.33	22.03	14.41	17.98
T8	Control	15.36	16.34	22.72	28.07	37.33	39.83	29.10	33.28	25.16	30.19
SEm±		**1.10**	**1.77**	**2.19**	**2.71**	**2.78**	**3.53**	**2.43**	**2.91**	**2.35**	**3.05**
CD (P=0.05)		**3.34**	**5.37**	**6.66**	**8.23**	**8.43**	**10.72**	**7.39**	**8.85**	**7.14**	**9.25**

Table 3. Effect of different components of natural farming on weed control efficiency in wheat+ gram cropping system

Treatment		Weed control efficiency (%)									
		60 DAS		90 DAS		120 DAS		150 DAS		At Harvest	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
T1	*Ghanjeevamrit* @ 5 q ha^{-1} before sowing	35.0	32.9	22.2	20.0	18.5	9.9	18.5	8.1	16.9	13.9
T2	*Jeevamrit* (foliar application at 21 days interval)	25.1	20.2	14.7	18.4	10.9	3.0	14.3	13.7	27.8	19.2
T3	Mulching @ 10 t ha^{-1}	47.3	45.5	34.7	33.4	31.2	28.4	37.4	32.4	38.8	33.6
T4	*Ghanjeevamrit* + *jeevamrit*	17.7	19.7	18.4	24.1	10.1	4.8	15.7	7.1	15.6	14.1
T5	*Ghanjeevamrit* + mulching	47.9	39.7	42.3	38.8	40.1	37.6	46.6	41.1	49.6	43.8
T6	*Jeevamrit* +mulching	45.4	46.1	42.5	43.3	33.6	26.7	42.9	37.0	42.0	43.8
T7	*Ghanjeevamrit* + *jeevamrit* + mulching	51.3	52.5	49.3	43.5	45.6	37.9	49.2	42.5	52.2	48.9
T8	Control	0	0	0	0	0	0	0	0	0	0

Table 4. Effect of different components of natural farming on number of root nodules per plant at 50% flowering in gram

Treatment		No. of root nodules plant^{-1}		Pooled data
		2019-20	2020-21	
T1	*Ghanjeevamrit @ 5 q* ha^{-1} before sowing	23.5	24.8	24.1
T2	*Jeevamrit* (foliar application at 21 days interval)	23.3	26.3	24.8
T3	Mulching @ 10 t ha^{-1}	22.0	23.7	22.8
T4	*Ghanjeevamrit + jeevamrit*	24.6	26.1	25.4
T5	*Ghanjeevamrit* + mulching	25.9	27.4	26.6
T6	*Jeevamrit* +mulching	23.9	26.3	25.1
T7	*Ghanjeevamrit + jeevamrit +* mulching	27.1	28.5	27.8
T8	Control	21.5	22.1	21.8
SEm±		**0.6**	**0.8**	**0.4**
CD (P=0.05)		**1.8**	**2.5**	**1.3**

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENTS

We are thankful to the Junagadh Agricultural University at Junagadh for providing the all necessary facilities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

References:

Berquer, A., Bretagnolle, V., Martin, O., & Gaba, S. (2023). Disentangling the effect of nitrogen input and weed control on crop–weed competition suggests a potential agronomic trap in conventional farming. *Agriculture, Ecosystems & Environment*, *345*, 108232.

Cheto, S., Oukaltouma, K., Chamkhi, I., Yasser, A., Benmrid, B., Qaddoury, A., … & Ghoulam, C. (2023). Inoculation with rhizobacterial consortia alleviates combined water and phosphorus deficit stress in intercropped faba bean and wheat. *Frontiers in Sustainable Food Systems*, 7. https://doi.org/10.3389/fsufs.2023.1147939

Choudhary, R., R. P. Sharma, N. Rana, P. Dev, G. D. Sharma, and R. Kumar (2022). Effect of natural farming on yield performances, soil health and nutrient uptake in wheat+ gram inter cropping system in sub-temperate regions of Himachal Pradesh. *Journal of Crop and Weed*, 18(2): 01-08.

El-Beltagi, H. S., Basit, A., Mohamed, H. I., Ali, I., Ullah, S., Kamel, E. A., ... & Ghazzawy, H. S. (2022). Mulching as a sustainable water and soil saving practice in agriculture: A review. *Agronomy*, *12*(8), 1881.

Ikeh, A. O., Amulu, L. U., Orji, J. O., Olufelo, J. O., & Umelo, C. Q. (2023a). Land use efficiency of castor (*Ricinus communis* L.) based cropping systems in Okigwe, Southeastern Nigeria. *Applied Research in Science and Technology*, *3*(2). *https://doi.org/10.33292/areste.v3i2.4*

Ikeh, A. O., Okocha, I. O., Umekwe, P. N., Amanze, A. N., & Ikeh, C. E. (2023b). Effect of foliar application of cow dung extract on growth and yield of waterleaf (*Talinum triangulare* Jacq.) in an ultisol. *Journal of Current Opinion in Crop Science*, *4*(3), 103-111. https://doi.org/10.62773/jcocs.v4i3.203

Ikeh, A. O., Ndaeyo, N. U., Iwo, G. A., Aderi, O. S., Ikeorgu, J. E. G., Nwachukwu, E..C & Essien, B. A. (2012). Effects of Cropping System on Growth and Yield of Yam (*Dioscorearotundata*) Genotypes and Egusi Melon (*Colocynths citrullus*) on an ultisol. *International Journal of Applied Research and Technology* 1:1:119-131.http://www.esxpublishers.com/images/2%20ijrt-0312-0224.pdf

Ikeh, A.O. and Akpan, E.A. (2018). Response of Dry Season Garden Egg (*Solanum melongena*) to Watering Regime and Organic Mulching Levels in Okigwe, Southeastern Nigeria. *Journal of Agricultural and Crop Research,* 6 (2):38-46.

Ikeh, A.O., Akata, O.R., Ukabiala, M.E., Okoro, N.J., Amanze, A.N. & Ayegba, E.O. (2023c). Maturation Period and Nitrogen Fixing Capacity of Some Cowpea (*Vigna* *unguiculata* L Walp) Varieties in Okigwe, Southeastern Nigeria. *Journal of Agriculture & Forestry Research*, 2 (5):65-73.

Ikeh, A.O., Udoh, E.I. & Opara, A.C. (2019). Effect of Mulching on Weed, Fruit Yield and Economic Returns of Garden Egg (*Solaniummelogena*) in Okigwe Southeastern Nigeria. *Journal of Research in Weed Science*, Volume 2(1):52-64.https://www.jrweedsci.com/article_81679.html.
Doi:10.26655/jrweedsci.2019.1.5

Kumar, S., Rana, S. S., Kumar, S., & Rana, B. B. (2022). Influence of organic weed management practices on floristic diversity and shifts in maize–pea cropping system. *Himachal Journal of Agricultural Research*, *48*(2), 189-195.

Leoni, F., Lazzaro, M., Ruggeri, M., Carlesi, S., Meriggi, P., & Moonen, A. (2022). Relay intercropping can efficiently support weed management in cereal-based cropping systems when appropriate legume species are chosen. *Agronomy for Sustainable Development*, 42(4). https://doi.org/10.1007/s13593-022-00787-3

Li, L., Li, S., Sun, J., Zhou, L., Bao, X., Zhang, H., … & Zhang, F. (2007). Diversity enhances agricultural productivity via rhizosphere phosphorus facilitation on phosphorus-deficient soils. Proceedings of the National Academy of Sciences, 104(27), 11192-11196. https://doi.org/10.1073/pnas.0704591104

Mechergui, T., Pardos, M., Jhariya, M. K., & Banerjee, A. (2021). Mulching and weed management towards sustainability. *Ecological intensification of natural resources for sustainable agriculture*, 255-287.

Naik, M., Rana, M. C., Sankhyan, N. K., Chauhan, S., Choudhary, R., & Rana, B. B. (2024). Growth, NPK Uptake and Crude Protein Content in Diversified Cropping System under Natural Farming. *International Journal of Plant & Soil Science*, *36*(10), 492-503. https://doi.org/10.9734/ijpss/2024/v36i105100

Narwal, K., Sharma, G. D., Kumar, N., Sankhyan N, K., Manuja, S., Rana, B. B., & Hetta, G. Assessing the Productivity of Forage Based Cropping System under Different Farming Practices in the Western Himalayan Region. *Journal of Experimental Agriculture International*, 46(4), 8-12. https://doi.org/10.9734/JEAI/2024/v46i42335

Rohi-Saralan, A., Shafagh-Kolvanagh, J., & Nassab, A. (2018). Omega-3 fatty acid in purslane (*Portulaca oleracea* l.) intercropped with dragon's head (lallemantia iberica fischer & c.a. meyer) as affected by mulching and biofertilizers. *Turkish Journal of Field Crops*, 23(2), 127-134. https://doi.org/10.17557/tjfc.471671

Sharma, T., Singh, J., Madaik, S., Kumar, P., Singh, A., Rana, B. B., & Chauhan, G. (2024). Organic input incorporation for enhancing sustainability and economic viability of cowpea in North-Western Himalayan region. *Frontiers in Agronomy*, *6*, 1458603. https://doi.org/10.3389/fagro.2024.1458603

Sharma, R., Manuja, S., Kumar, N., Sharma, R.P., Saharan, S., Sharma, T., & Rana, B. B. (2023). Effect of foliar spray of nanonitrogen and nano zinc on growth, development, yield, and economics of rice (*Oryza sativa* L.). *The Pharma Innovation.*

Shehata, S.A.; Abouziena, H.F.; Abdelgawad, K.; Elkhawaga, F.A. (2019). Weed Control Efficacy, Growth and Yield of Potato (*Solanum tuberosum* L.) as Affected by Alternative Weed Control Methods. *Potato Res. 62*, 139–155

Veisi, M. (2020). *Journal of plant protection research*. https://doi.org/10.24425/jppr.2020.132212

Yin, W., Fan, Z., Hu, F., Fan, H., Yu, A., Zhao, C., … & Chai, Q. (2019). Straw and plastic mulching enhances crop productivity via optimizing interspecific interactions of wheat–maize intercropping in arid areas. *Crop Science*, 59(5), 2201-2213. https://doi.org/10.2135/cropsci2019.02.0082

Yin, W., Fan, Z., Hu, F., Yu, A., Zhao, C., Chai, Q., … & Coulter, J. (2019). Innovation in alternate mulch with straw and plastic management bolsters yield and water use efficiency in wheat-maize intercropping in arid conditions. *Scientific Reports*, 9(1). https://doi.org/10.1038/s41598-019-42790-x

Zhang, X., Jiang, H., Wan, X., & Li, Y. (2020). The effects of different types of mulch on soil properties and tea production and quality. *Journal of the Science of Food and Agriculture*, 100(14), 5292-5300. https://doi.org/10.1002/jsfa.10580