Journal of Advances in Biology & Biotechnology

Volume 27, Issue 11, Page 1349-1356, 2024; Article no.JABB.126616
ISSN: 2394-1081

Synergistic Effects of Mulching and Integrated Nutrient Management Practices on Maize *(Zea mays)*

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i111722

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/126616

Original Research Article

Received: 15/09/2024
Accepted: 17/11/2024
Published: 27/11/2024

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Cite as: *Priyanka, Elumle, K. Kurmi, Kalyan Pathak, Indra Jeet, Narinder Panotra, Kushal Sachan, S. Anbarasan, and Himanshu Sekhar Behera. 2024. "Synergistic Effects of Mulching and Integrated Nutrient Management Practices on Maize (Zea Mays)". Journal of Advances in Biology & Biotechnology 27 (11):1349-56. https://doi.org/10.9734/jabb/2024/v27i111722.*

ABSTRACT

The two yearlong experiment was conducted at the ICR Farm of sandy loam and acidic soils at Assam Agricultural University, Jorhat during the *rabi* season of 2020-21 and 2021- 22. The experiment was laid out in split plot design with 3 replications with 3X8 treatments. The treatment consisted of three mulching treatments M_0; No mulch, M_1:Paddy straw mulch @6t/ha and M_2: Biodegradable plastic film of 20µ in the main plots, and INM practices as sub-plots such as I_1: 100% recommended dose of fertilizers (RDF), I_2 :100% RDF + Water spray, I_3: 100% PK + 75% RDN + 25% Vermicompost (VC), I_4:100% PK + 75% RDN + 25% Enriched compost(EC) , I_5:100% PK + 75% RDN + 25% VC + 4% Vermiwash, I_6: 100% PK + 75% RDN + 25%EC + 4% Vermiwash, I_7:100% PK + 75% RDN + 25% VC + 4% Humic acid, I_8:100% PK + 75% RDN + 25% EC + 4% Humic acid. Maize variety DKC 9081 was selected for research. Results revealed that the different soil moisture conservation practices significantly affected the growth parameters like plant height, dry matter accumulation and yield attributes of *rabi* maize. The maximum values of growth parameters were recorded in the treatment involving application of biodegradable plastic mulch. Similar effects were obtained in yield and yield attributing characters *viz*., weight of cob with and without husk, number of rows per cob, grain per row, grain per cob, 1000 grain weight, , grain yield pooled over two years (79.06 q/ha). Among the INM practices the treatment with 100% PK+75% RDN+25% Enriched compost +4% Humic acid (I8) resulted in significantly higher growth parameters like plant height, leaf area, leaf area index and dry matter accumulation of *rabi* maize. Similarly, yield and yield attributing characters *viz*., weight of cob with and without husk, length of cob, number of rows per cob, grain per row, grain per cob, 1000 grain weight and grain yield (77.56 q/ha) were also higher under this treatment.

Keywords: Biodegradable film mulch; enriched compost; integrated nutrient management; humic acid; vermicompost; vermiwash.

1. INTRODUCTION

Maize is a major staple food for one-third of the world's population. Over 170 nations are currently producing jointly 1147.7 million MT of maize on 193.7 million hectares of land, with an average productivity of 5.75 t ha^{-1}(FAO STAT, 2020). Maize during *rabi* takes up about 16.93 lakh hectares. The largest states that grow maize are Bihar (5.27 million hectares), Maharashtra (2.27 million hectares), West Bengal (1.52 million hectares), and Assam (31,000 hectares), which produces 91,000 tonnes of the grain each year at a productivity of 2911kg ha^{-1} (FAO STAT, 2020). Maize is regarded as the third most important cereal crop after wheat and rice (Murdia et al*.,* 2016). Low yield in maize is caused by variety of biotic and abiotic factors such as nutrient inadequacy, moisture stress, insect pest attack, unpredictable rainfall behavior and other environmental variables. There is nutrient deficit due to abiotic factors including high nutrient fixation in acidic soil and water scarcity during *rabi* season. To avoid these, suitable measures for soil moisture conservation and integrated nutrient management practices were carried out. Mulch is defined as any material placed on soil surface to retain moisture, which reduces evaporation losses by acting as a barrier to the movement of soil moisture. Paddy straw mulching is considered to be a green and sustainable mulching technology (Zhao et al., 2019) The use of biodegradable film in place of conventional polyethylene might be the best way to improve the yield at the moment, (Moreno,2008). On the other hand, Heavy use of chemical fertilizers alone is causing soil deterioration, degradation of soil and organic matter (Nottidge et al*.,* 2005) Vermicompost is enriched with vitamins, enzymes and enhance microbial and enzyme activity, fine particle structure, good moisture-holding capacity and includes nutrients like N, P, K, Ca, and Mg in forms that plants can easily absorb (Moridi et al.,2019). Vermiwash is a liquid waste extract that is gathered after water has passed through the various layers of an earthworm culture unit. It is used as foliar spray in improving yield of crops (Raviv,1998). Humic acid increase crop growth by increasing plant growth promoting hormones such as auxin and cytokinin, which aid in stress resistance, nutrients metabolism, and photosynthesis (Canellas et al., 2020).

A simple and very low-cost effective technique of in situ soil moisture conservation in maize (*Zea mays* L.) was mulching with locally available paddy straw and biodegradable film mulches and nutrient requirement by crop can be fulfilled by integrating nutrient management practices.

Therefore the present study was initiated with the objectives of study on effects of soil moisture conservation and integrated nutrient management practices on the growth and yield of *rabi* maize in experimental site.

2. MATERIALS AND METHODS

The geographical location of the Instructional cum Research Farm of Assam Agricultural University, Jorhat is situated at 26º45'N latitude, 94º12'E longitude and at an altitude of 87m above mean sea level (MSL). A field with homogeneous soil fertility, good drainage, and uniform texture was used for the experiment. Jorhat, included in the upper Brahmaputra valley agro-climatic zone of Assam, has a subtropical humid climate with warm summers and cool winters. It receives 2500mm of annual rain on average. June marks the beginning of the monsoon, which lasts through September. In second half of March, pre-monsoon showers are also experienced in the region. Rainfall intensity is highest from June to July and peaks in August. It then progressively declines, with December and January seeing the least amount of precipitation. Along with rain, temperature also rises gradually.

2.1 Experimental Materials, Design and Details

The experimental field was thoroughly prepared for sowing using a tractor-drawn disc board plough, and in last week of November 2020, two harrowings were completed, followed by laddering. The plots were cleared of any trash, plant matter that hadn't decomposed. The field was set up according to the experimental design after being properly prepared for use. Seeds of hybrid maize variety, DKC-9081 were sown on 1st December, 2020 and 26th November, 2021. Sowing was done manually by dibbling method at a spacing 60 cm x 25 cm by using a seed rate of 22.5 kg ha^{-1}. Two levels of mulch treatment comprising paddy straw and biodegradable plastic film were compared with no mulch control treatment for soil moisture conservation and weed suppression in *rabi* maize. Before sowing Paddy straw mulch (M_1) was applied @ 6t ha^{-1} and biodegradable plastic film mulch (M_2) of 20 micron (µ) thickness was placed over the plots. Required amount of nitrogen, phosphorus and potassium in the experimental field was supplied through urea, SSP and MOP, respectively, and through VC and EC as per treatments. The experiment was laid out in split plot design replicated thrice with three mulching treatments M_0; No mulch, M_1:Paddy straw mulch @6t/ha and M_2: Biodegradable plastic film of 20µ in the main plots and INM practices as sub-plots such as I_1: 100% recommended dose of fertilizers (RDF), I_2 :100% RDF + Water spray, I_3: 100% PK + 75% RDN + 25% Vermicompost (VC), I_4:100% PK + 75% RDN + 25% Enriched compost(EC) , I_5:100% PK + 75% RDN + 25% VC + 4% Vermiwash, I_6: 100% PK + 75% RDN + 25%EC + 4% Vermiwash, I_7:100% PK + 75% RDN + 25% VC + 4% Humic acid, I_8:100% PK + 75% RDN + 25% EC + 4% Humic acid.

2.2 Biometric Observations

Measurements of various growth and yield attributing characters were recorded prior to harvesting of the crop to assess the treatment effects. Five plants were tagged to observe the significant difference between the treatments. The height of each selected five plants were measured in cm from ground level to the tip of the topmost leaf or tassel and the average was calculated for each plot. For dry weight the plants were chopped and sun-dried for 48 hours, packed in brown paper bags, and then dried at 60 ± 5ºC until they reached a constant weight. The samples dry weights were quantified in grams. At harvest, the number of grains per cob was calculated. The weight of the total grains from each plot were weighed and converted into quintal per hectare for estimation of grain yield. The weight of 1000 grains was then measured as test weight according to treatment and stated in grams. The shelling percentage was calculated by dividing weight of grains with weight of cobs, expressed in percentage.

2.3 Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) statistical software suggested by Panse and Sukhatme (1978) and least significant differences/critical dfferences were done at 5% probability levels for all treatments at experimental site

3. RESULTS AND DISCUSSION

Plant height and dry matter: The mean plant height and dry matter accumulation (Table 1) of rabi maize during both the years was found to increase progressively over time and attained the highest value when it was harvested at physiological maturity stage (120 DAS). M_2 exhibited the highest plant height (202.58 cm), followed by M_1 (184.60 cm) and M_0 (179.70cm).

Table 1. Effect of mulches and Integrated Nutrient Management practices on plant height and dry matter accumulation of *rabi* maize

Treatments	Plant height(cm)				Dry matter accumulation (g)			
	30 DAS	**60 DAS**	**90 DAS**	**120 DAS**	**30 DAS**	**60 DAS**	**90 DAS**	**120 DAS**
Main plot treatments								
M_0	21.79	56.82	163.64	179.77	9.41	34.63	74.80	93.73
M_1	25.62	64.37	174.80	184.60	11.02	42.03	83.02	104.17
M_2	24.78	74.33	193.26	202.58	11.18	49.31	91.14	124.33
SEm±	0.690	0.913	1.498	3.146	0.099	0.929	1.070	1.732
CD (P=0.05)	2.711	3.584	5.881	12.352	0.387	3.647	4.199	6.798
Sub-plot treatments								
I_1	22.68	58.73	168.03	179.84	9.97	38.91	79.26	103.97
I_2	22.80	58.67	169.72	181.81	9.88	39.22	80.11	105.31
I_3	23.87	65.27	172.58	186.39	10.44	40.71	81.71	106.32
I_4	24.68	65.95	175.99	187.73	10.34	41.76	82.96	107.36
I_5	24.47	66.55	178.48	189.04	10.47	42.31	83.68	108.17
I_6	25.90	68.65	186.06	195.73	11.12	43.98	84.93	108.44
I_7	23.72	67.28	180.99	192.65	10.79	42.95	84.57	109.44
I_8	24.40	70.30	186.03	198.69	11.30	46.11	86.67	110.28
SEm±	0.935	1.323	1.856	3.091	0.382	1.397	1.237	2.055
CD (P=0.05)	*	3.776	5.296	8.822	NS	3.988	3.530	*

Table 2. Effect of soil moisture conservation and Integrated Nutrient Management practices on yield and yield attributes of *rabi* maize

Treatments	Grains/cob(g)		Weight of grains/cob(g)		Shelling percentage (%)		Test weight(g)		Grain yield(q/ha)	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Main plot treatments										
M0	273.44	277.21	78.71	85.65	76.42	77.08	271.44	272.14	64.58	68
M_1	294.69	294.83	96.6	102.84	76.87	78.5	276.82	277.31	66.88	73.78
M_2	408.83	416.87	116.48	132.24	77.5	80.98	282.85	282.05	76.25	81.88
SEm±	4.826	6.02	2.065	1.971	0.958	1.581	1.648	1.372	1.413	0.993
CD (P=0.05)	18.947	23.635	8.109	7.739	NS	NS	6.47	5.385	5.547	3.899
Sub-plot treatments										
I_1	302.41	307.61	92.6	98.26	74.88	78	275.7	275.64	64.3	70.62
I_2	309.15	308.88	93.34	100.5	75.2	79.27	274.88	275.75	65.24	71.36
I_3	317.96	322.86	94.84	103.82	75.58	78.16	276.68	277.07	66.07	72
I_4	321.05	326.57	94.91	105.03	75.29	76	276.4	277.18	67.1	73.17
I_5	329.26	334.26	99.1	108.51	77.09	80.15	276.9	277.15	69.48	76.3
I_6	338.83	344.52	100.43	111.75	77.84	79.45	276.82	277.37	73.94	77.14
I_7	335.84	341.34	100.45	111.11	78.81	79.58	278.93	278.3	72.1	76.38
I_8	350.71	351.05	102.42	116.31	80.75	80.22	279.97	278.87	75.67	79.44
SEm±	6.918	7.719	2.157	3.013	1.498	1.821	1.475	1.161	1.391	1.502
CD (P=0.05)	19.746	22.031	6.157	8.601	*	*	*	*	3.97	4.286

Plant height varied among the INM treatments, with I_8 (100% PK + 75% RDN + 25% EC + 4% Humic acid) consistently showing the highest values across all stages, peaking at 198.69 cm at 120 DAS. I_6 (100% PK + 75% RDN + 25% EC + 4% Vermiwash) also performed well, particularly notable at 120 DAS with a plant height of 195.73 cm. Similar pattern was followed with dry matter accumulation (Table 1) M_2 exhibited the highest dry matter accumulation across all stages, with 11.18 g/plant at 30 DAS, 49.31 g/plant at 60 DAS, 91.14 g/plant at 90 DAS, and 124.33 g/plant at 120 DAS. M_1 showed moderate results, whereas M_0 had the lowest dry matter accumulation, indicating the beneficial impact of mulching on biomass production. The results are in accordance with Cihangir (2020). Mulching provides enhanced crop microclimate through provision of improved rainwater harvesting and utilization, which helps in maintaining higher leaf turgor, elongation rate and overall photosynthesis for improved C fixation in terms of dry matter production and plant height (Singh et al*.,* 2022). Among the INM practices, I_8 demonstrated the highest dry matter accumulation, reaching 11.30 g/plant at 30 DAS and increasing significantly to 110.28 g/plant at 120 DAS. I_6 and I_7 also showed high dry matter accumulation after I_8, indicating the positive effect of combining organic amendments with chemical fertilizers. I_1 consistently recorded the lowest values, highlighting the limitation of using only the recommended dose of fertilizers without additional organic inputs. The impact of humic acid on certain plant processes like respiration and photosynthesis, as well as the improvement in photosynthesis efficiency and the subsequent provision of food stocks that then move to the seeds that are formed and increase the fullness and then increase growth and yield. The vermiwash showed better results after humic acid. This is explained by slower nutrient release for absorption with extra nutrients like gibberellin, cytokinnin, and auxins, as well as by the use of organic inputs in conjunction with vermiwash supported by Raviv (1998).

Grain yield, weight of grains/cob, Shelling Percentage, Test weight and grain yield: The impact of different soil moisture conservation practices and INM practices on grain yield and yield parameters across two growing seasons 2020-21 and 2021-22 was shown in Table 2. During both years, the treatments revealed notable differences in the number of grains per cob, weight of grains per cob, shelling percentage, test weight, and grain yield. The M_2 treatment exhibited the highest number of grains per cob at 408.83, significantly outperforming M_1 (294.69) and M_0 (273.44) during 2020-21 and M_2 (416.87), M_1 (294.83) and M_0 (277.21) during 2021-22. M_2 also showed the highest weight of grains per cob at 116.48 g, compared to 96.6 g in M_1 and 78.71 g in M_0. The weight of grains per cob during 2021-22 in M_2 increased to 132.24 g, significantly higher than 102.84 g in M_1 and 85.65 g in M_0, showing continued improvement. The shelling percentage was slightly higher in M_2 at 77.5% compared to 76.87% in M_1 and 76.42% in M_0, indicating a marginal improvement in grain filling with advanced practices. Similarly, M_2 exhibited the highest shelling percentage at 80.98%, compared to 78.5% in M_1 and 77.08% in M_0 indicating better grain filling in advanced treatments in second season. However, our research found no significant differences in shelling percentage between the different mulching and integrated nutrient management (INM) treatments across both the years.

The test weight followed a similar trend, with M_2 showing the highest value at 282.85 g, M_1 at 276.82 g, and M_0 at 271.44 g in 2020-21 and M2 at 282.05 g, with M_1 and M_0 at 277.31 g and 272.14 g, respectively in 2021-22, showing stable test weight. The maximum test weight was observed in the M_2 treatment, which employed mulching. The grain yield was highest in M_2 at 76.25 kg/ha, compared to 66.88 kg/ha in M_1 and 64.58 kg/ha in M_0, highlighting the significant yield advantage of advanced soil moisture conservation practices. Grain yield in M_2 further increased to 81.88 kg/ha, compared to 73.78 kg/ha in M_1 and 68 kg/ha in M_0, underscoring the sustained yield benefits of advanced soil moisture practices. The sub-plot treatments (I_1 to I_8) also showed significant variations.The number of grains per cob ranged from 302.41 in I_1 to 350.71 in I_8, with I_8 showing the highest values, reflecting the effectiveness of more intensive conservation practices. The number of grains per cob ranged from 307.61 in I_1 to 351.05 in I_8, with I_8 maintaining the highest values, confirming the effectiveness of intensive conservation practices.The weight of grains per cob varied from 92.6 g in I_1 to 102.42 g in I_8, again indicating superior performance with more intensive practices. Weight of grains per cob increased across all treatments, with I_8 showing the highest at 116.31 g, up from 102.42 g the previous year. Shelling percentage ranged from 74.88% in I_1 to 80.75% in I_8, suggesting better grain filling. Shelling percentage was highest in I_8 at 80.22%, reflecting improved grain filling in intensive treatments. Test weight varied from 275.7 g in I_1 to 279.97 g in I_8, with higher values indicating better grain quality. Test weight remained high, with values ranging from 275.64 g in I_1 to 278.87 g in I_8, indicating consistent grain quality. Grain yield ranged from 64.3 kg/ha in I_1 to 75.67 kg/ha in I_8.The highest grain yield observed at I_8 with 79.44 kg/ha these findings are in accordance with Misra et al.,1996 who found that soil mulching increased the amount of moisture that could be stored in the soil profile and considerably improved plant water use efficiency and plant overall growth and yield during both the years which contribute in increasing grains per cob. This suggests that M_2 not only increases the plant morphological characters but also enhance the yield parameters such as number of grains and also increases grain weight. This finding aligns with the study Chakraborty, (2008) which also reported enhanced grain weight under mulched conditions due to improved soil moisture retention. The non significant results for shelling percentage is in consistent with previous research indicating that shelling percentage is largely influenced by genetic factors and the physical characteristics of the cob and kernels rather than agronomic practices Li, J (2003). This increase in test weight can be attributed to the enhanced soil moisture availability provided by mulching during critical growth periods. Mulching helps in conserving soil moisture by reducing evaporation, thereby ensuring that plants have a consistent water supply, which is crucial for achieving maximum yield parameters. Chakraborty (2008) who reported similar benefits of mulching in improving grain weight due to better soil moisture conservation. Among INM practices, maximum values obtained with I_8:100% PK+75% RDN+25% EC+ 4% Humic acid which was at par with I_6 which formed by the combination of EC + vermiwash. Significant difference in grain yield /hectare (75.67q/ha in 2020-21, 79.44q/ha in 2021-22) was noticed among INM treatments, The percent (%) yield increase by INM treatments was 17.68 % and 12.4% during both the years in combination such as enriched compost with humic acid and with enriched compost and vermiwash showed 73.19 q/ha (12.13%) and 77.14 q/ha (8.15%) better results. Whereas, the combination of vermicompost and humic acid increased yield to 14.99% and 9.23 % during both the years.

4. CONCLUSION

Based on two years of field experimentation, it is concluded that the different mulch materials were found to be advantageous in improving crop microclimate through enhanced soil moisture, which increased the crop growth, physiological and photosynthetic performance for higher grain growth and yield of maize in *rabi* season. Across different integrated nutrient management practices, the application of 100% PK and 75% RDN along with enriched compost and foliar spray of 4% humic acid were observed to increase overall plant growth and yield.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/126616