



Effect of Tillage and Nutrient Management Practices on Normalized Difference Vegetation Index of Maize

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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/ijpss/2024/v36i84920>

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/121849>

Original Research Article

Received: 10/06/2024

Accepted: 12/08/2024

Published: 16/08/2024

ABSTRACT

Aims: The aim of the experiment was to study the NDVI values of maize crop at knee height stage and pre tasseling stage as an indicator of crop health under different tillage practices and precision nutrient management strategies.

Study Design: The experiment was conducted in split plot design using six tillage practices (Conventional Tillage, Conventional Tillage + Chisel Plough, Permanent Ridges, Permanent Bed,

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Cite as: Naithani, Pragya, Amit Bhatnagar, Subhash Chandra, Poonam Gautam, Rajeew Kumar, and Gurvinder Singh. 2024. "Effect of Tillage and Nutrient Management Practices on Normalized Difference Vegetation Index of Maize". *International Journal of Plant & Soil Science* 36 (8):893-901. <https://doi.org/10.9734/ijpss/2024/v36i84920>.

Zero Tillage and Minimum Tillage) in main plots and three nutrient management strategies [Site-Specific Nutrient Management (SSNM), GreenSeeker guided nitrogen application (GS), and 100% Recommended Dose of Nutrients (RDN)] in sub plots.

Place and Duration of Study: The field experiment was conducted at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, India, for two years *i.e.*, 2022 and 2023.

Methodology: Conventional tillage involved two passes of harrowing and one rotavator. Conventional tillage + chisel plough included the additional use of a chisel plough after every four years. In permanent ridge and permanent bed strip, raised soil configurations were reshaped after every crop. In zero tillage, land preparation was limited to opening of seed furrows and crop was sown directly. In minimum tillage field was tilled through only with single pass of rotavator. In SSNM using “Maize Nutrient Expert” nutrient application was done at the rate of 130:33:66 kg N: P₂O₅: K₂O per ha. Under GS treatments maize nitrogen application was done as (40 + GS) N per ha. The 100% RDN for maize was 120:60:40 kg N: P₂O₅: K₂O per ha.

Results: Results indicated significant variations in NDVI values at knee height stage and at pre tasseling stage due to different tillage practices where zero tillage and conventional + chisel plough were found significantly superior. NDVI values among nutrient management strategies were not statistically different. Correlation studies concluded that NDVI of *kharif* maize crop is negatively correlated to minimum temperature, maximum temperature, number of rainy days and amount of rainfall received. Zero tillage and conventional + chisel plough sustain crop health even under excess rainfall conditions.

Conclusion: Zero tillage and conventional + chisel plough can be advocated for the better health of *kharif* maize crop even under varied weather conditions.

Keywords: Chisel plough; Greenseeker; minimum tillage; NDVI; site-specific nutrient management; zero tillage.

1. INTRODUCTION

Maize is cultivated in over 170 countries, covering 193.7 million hectares and boasts the highest productivity among cereals at 5.9 tons per hectare with a total production of 1147.7 million ton [1]. As a C4 plant, maize is efficient in maintaining crop health even with climate change impacts. Modern researches are focused on improving resilience of maize crop to climate change through genetic engineering, resilient crop management and precision agriculture. Recent researches promote conservation practices such as zero tillage and minimal tillage to improve soil health and water retention thereby increasing resilience of maize to climate variability. Uses of precision technologies in maize like sensors, GIS, GPS are in the trend to monitor crop health and environmental conditions in real-time. Precise application of inputs based on field variability, optimizes resource use and enhances crop resilience. Moreover, the significant gap between global and national productivity (2.3 tons per hectare) [1] highlights the need for adopting modern crop production technologies instead of conventional practices which reduce the influence of weather adversities on crop health. The adoption of recent advancements in tillage and precision nutrient management may boost maize growth and thereby productivity even with environmental

stress. Unlike conventional tillage, modern tillage improves soil health, soil structure, organic matter content, and moisture retention [2], promoting crop resilience. By protecting the soil surface, conservation tillage reduces erosion, maintains soil fertility and contributes to better growth and yields [3]. Precision nutrient management practices are known to enhance nutrient use efficiency, productivity and profitability in accordance with environmental sustainability [4]. Crops show significant responses to precise nutrient applications, reflected in increased chlorophyll content and higher NDVI values soon after application. Consistent, precise nutrient management ensures that crops receive the right amount of nutrients throughout the growing season, promoting optimal growth [5].

Combining modern tillage with precision nutrient management creates a synergistic effect that significantly enhances crop health [6]. Long-term modern tillage and nutrient management improves overall soil fertility, supporting healthier crops and sustained higher NDVI values over multiple growing seasons [7]. Together, these practices contribute to improved crop health and promote more stable and sustainable crop production [8].

Crop health indicators are essential for assessing the impact of agricultural inputs on crops. These

indicators include visual cues (such as leaf color, shape, size, and vigor) and physiological measures (such as chlorophyll content measured with SPAD meters and stomatal conductance), which help to evaluate crop health at various growth stages and the effects of treatments of crop. The Normalized Difference Vegetation Index (NDVI) is a numerical indicator derived from the visible and near-infrared bands of the electromagnetic spectrum and is used to determine the presence of live green vegetation [9]. Based on remote sensing principles, NDVI assesses vegetation health, biomass, and chlorophyll content, making it a vital tool for monitoring crop growth and development and providing critical information for agronomic decision-making. NDVI values range from -1 to +1, and they are calculated using the following formula:

$$NDVI = \frac{NIR_{ref} - R_{ref}}{NIR_{inc} + R_{inc}}$$

Where:

NIR (Near-Infrared): Reflectance in the near-infrared region of the spectrum.

R: Reflectance in the red region of the spectrum.

ref: Reflected

inc: incident

NDVI values close to +1 indicate healthy, dense green vegetation while values close to zero suggest sparse vegetation or bare soil. Healthy, photosynthetically active vegetation reflects more near-infrared (NIR) light and less visible light, resulting in higher NDVI values. It detects plant stress caused by factors such as nutrient deficiencies, allowing for timely interventions. High NDVI values generally correlate with higher biomass and potential yield.

Considering the foresaid points, an experiment was planned to assess the health and performance of maize crop under modern tillage and precision nutrient management practices through NDVI reflectance. The objective of the experiment was to study the NDVI values of maize crop at knee height stage and pre tasseling stage as an indicator of crop health, under different tillage practices and precision nutrient management strategies. By understanding these effects, the study aims to provide insights into optimizing tillage and nutrient management practices for improved crop health and yield.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was conducted in E-2 block (Maize Agronomy block) of Norman E. Borlaug Crop Research Centre at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand, India. The field experiment was conducted for two years (2022 and 2023). The site is situated at an altitude of 243.84 m above mean sea level, at 29° N latitude and 79.5° E longitudes under narrow belt of Shivalik foothills called *Tarai*. Accounts of weather parameters during experimental period were obtained from the meteorological observatory located at N. E. Borlaug Crop Research Centre, Pantnagar and are depicted in Fig. 1.

2.2 Treatment Details

The experiment was a part of long term field study initiated in 2012. Conducted using a Split-Plot Design with three replications, the main plot treatments consisted of six tillage practices: conventional tillage, conventional tillage + chisel plough, permanent ridges, permanent bed, zero tillage and minimum tillage. Conventional tillage involved two passes of harrowing and one rotavator to prepare the seedbed. conventional tillage + chisel plough included the additional use of a chisel plough after every four years to break up compacted soil layers, improving root penetration and water infiltration. In permanent ridge and permanent bed strip, raised soil configurations that were made in 2012 remained intact throughout multiple growing seasons and were reshaped after every crop. In zero tillage, land preparation was limited to opening of seed furrows and crop was sown directly. Minimum tillage omitted few tillage operations that were performed under conventional tillage and only single pass of rotavator was done.

The sub-plot treatments included three nutrient management strategies: Site-Specific Nutrient Management (SSNM), GreenSeeker Guided Nitrogen Application (GS) and 100% Recommended Dose of Nutrients (RDN). SSNM involved tailoring nutrient applications to the specific needs of different field zones based on soil tests, crop requirements and yield goals. This approach optimizes nutrient use efficiency and minimizes environmental impact. Using "Maize Nutrient Expert" nutrient application was done at the rate 130:33:66 kg N: P₂O₅: K₂O per ha. GreenSeeker is a precision agriculture tool

that uses optical sensors to assess crop health and guide variable-rate nitrogen applications. It ensures that nitrogen is applied where and when it is needed most, improving nitrogen use efficiency and crop yield. Under GS treatments maize nitrogen application was done as (40 + GS) N per ha. 40 kg N per ha was given as prescriptive basal dose and top dressing at knee height and pre tasseling stage was done as GreenSeeker guided nitrogen application. Prior

to applying fertilizer, NDVI readings from both N-rich strip and test plots were collected and used to calculate urea application dose. The 100% RDN strategy involved applying the full recommended dose of nutrients based on general crop requirements and soil tests. While it ensures sufficient nutrient availability, it may not account for spatial variability within the field. The recommended dose of nutrients for maize is 120:60:40 kg N: P₂O₅: K₂O per ha.

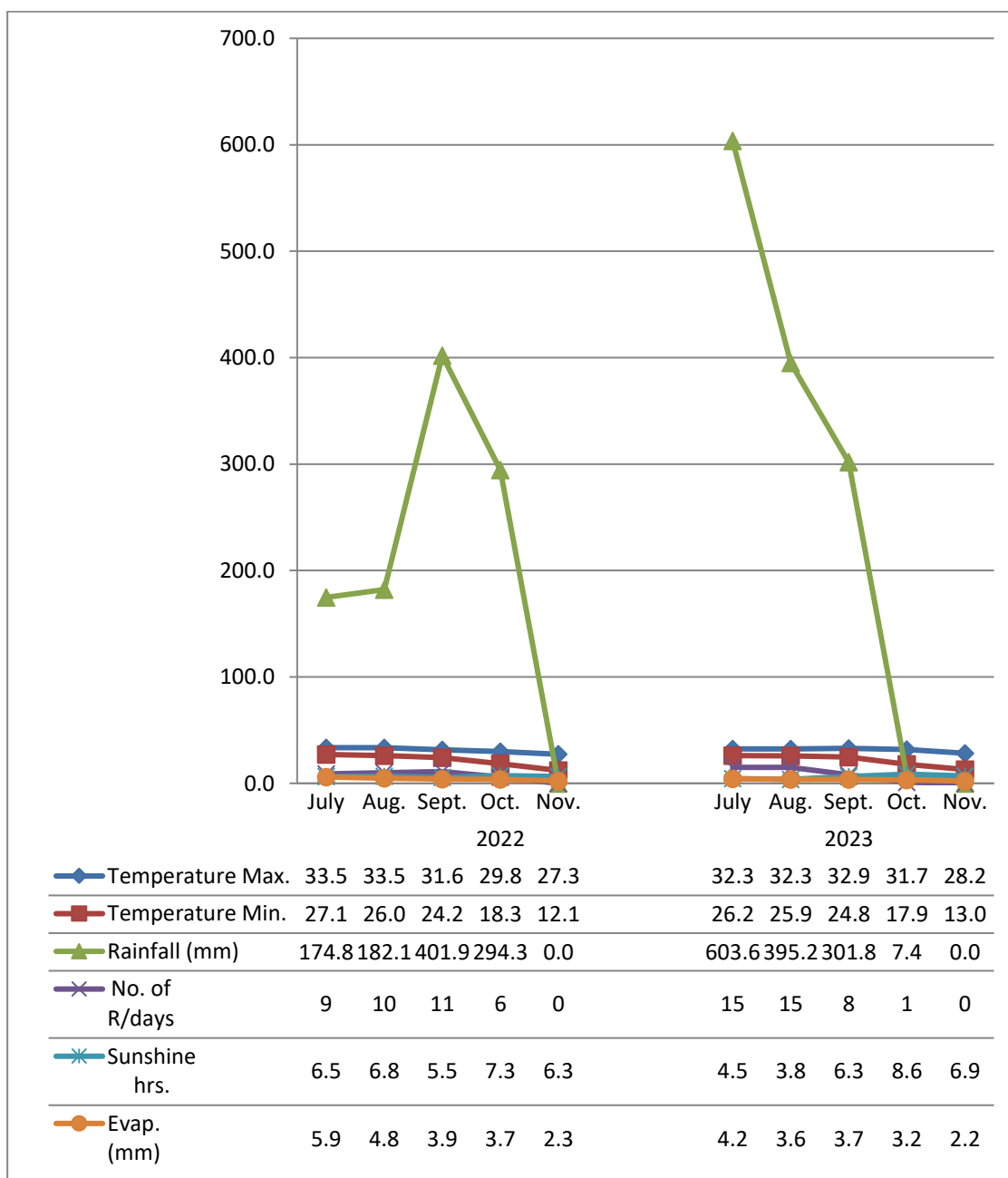


Fig. 1. Meteorological parameters during the years of experimentation (Kharif 2022 and Kharif 2023) recorded at the meteorological laboratory of NEB, Crop Research Centre, GBPUAT, Pantnagar

2.3 Recording of NDVI Values

A handheld GreenSeeker was used to determine NDVI value of crop and monitor crop health under different treatments. NDVI values were determined at knee height stage, *i.e.*, 33 days after sowing (DAS) and pre tasseling stage *i.e.*, 55 DAS of maize. GreenSeeker was used after 3 pm in the afternoon on a clear sunny day to avoid the direct interference of overhead sunlight in estimation. The instrument was held at 60 cm above the crop canopy while the trigger was pulled. The instrument thereafter displayed the measured NDVI reading on the LCD display immediately.

2.4 Statistical Analysis

Data for NDVI reading was analyzed for variance at the 5% level of significance using Fisher's method of analysis of variance. Significant treatment differences were evaluated using the value of critical difference. Statistical analysis of all parameters was carried out utilizing the split-plot design methodology as described by Gomez and Gomez [10] with the help of OPSTAT software. For better understanding of the external factors influencing crop health correlation was calculated between meteorological observations and NDVI recorded. The OriginPro 2024b software was used for correlation studies between NDVI values of maize and weather parameters.

3. RESULTS AND DISCUSSION

3.1 Effect of Tillage Practices on NDVI of Maize

NDVI value increased with advancement in crop age from 33 DAS to 55 DAS in all tillage treatments. Data (Table 1 and Fig. 2) revealed that at 33 DAS in 2022, field preparation through conventional tillage + chisel plough exhibited the highest NDVI reflectance (0.792) which was at par with zero tillage (0.787), indicating robust early vegetative growth in these tillage practices. These treatments were significantly superior to conventional tillage (0.711), permanent ridge (0.724), permanent bed (0.730) and minimum tillage (0.753). Minimum tillage had moderate NDVI value, which was statistically at par with permanent bed and permanent ridge while it was significantly more than conventional tillage. At 33 DAS in 2023, zero tillage (0.741) and conventional tillage + chisel plough (0.739)

showed the significantly higher NDVI values, which were at par with minimum tillage (0.719) but statistically outperformed conventional tillage (0.698), permanent bed (0.710) and permanent ridge (0.700). Maize crop grown under conventional tillage, permanent bed and permanent ridge showed poor reflectance and these treatments were statistically at par with each other in second year of experimentation.

At 55 DAS in 2022, the conventional tillage + chisel plough treatment maintained the highest NDVI value (0.811) which was statistically similar to zero tillage (0.810) and minimum tillage (0.803) while was significantly superior to permanent ridge (0.786) and permanent bed (0.782) and minimum tillage (0.777). In 2023, both zero tillage and conventional tillage + chisel plough showed the highest NDVI values (0.785) and these two tillage practices being at par with minimum tillage had significantly more value than conventional tillage (0.764), permanent bed (0.762) and permanent ridge (0.765). Higher value of NDVI in zero tillage, conventional tillage + chisel plough and minimum tillage indicated better growth in these tillage practices.

Amongst tillage treatments, zero tillage and conventional with chisel plough resulted in higher NDVI as was also reported by Cai et al. [11] and Pramanick et al. [6]. Higher soil organic matter and better soil aggregation in zero tillage plots after ten years of practice have contributed to better crop growth and ultimately higher NDVI values [12,13]. Chiseling allows more root penetration as compared to conventional tillage [14,15] and thereby permits extraction of nutrients from deeper soil profile [16]. Moreover, chisel ploughing made more availability of nutrients from increased area of exploration by roots, improved crop health and resulted into higher reflectance and thus more NDVI value.

3.2 Effect of Nutrient Management Strategies on NDVI of Maize

An increase in NDVI value among all nutrient management practices was observed as crop age advanced from 33 DAS to 55 DAS (Table 1). Data presented in Table 1 clearly indicated that at 33 DAS the NDVI values among nutrient management practices in 2022 were not significantly different. Similarly, in 2023, GS (0.725), SSNM (0.716) and RDN (0.712) showed non-significant differences. At 55 DAS in 2022, the GS treatment had the highest NDVI value (0.807), although it was not significantly superior

to the other treatments. The SSNM and 100% RDN treatments (0.790 and 0.793, respectively) were at par with each other. In 2023, NDVI values at 55 DAS did not vary significantly due to different nutrient management treatments where GS (0.777) showed a marginally higher NDVI value than SSNM (0.770) and 100% RDN (0.770).

In the nutrient management treatments, adequate amount of nutrient application satisfied vegetative nutrient demand of crop. At par crop health in all nutrient management treatments

resulted in to non-significant differences in reflectance of crop.

3.3 Correlation between Weather Parameters and NDVI of Maize

Correlation between weather parameters and crop NDVI was worked out which confirmed that number of rainy days ($r^2 = -0.77$), amount of rainfall received ($r^2 = -0.46$), maximum temperature ($r^2 = -0.61$) and minimum temperature ($r^2 = -0.85$) are negatively correlated with NDVI reflectance (Fig. 3).

Table 1. NDVI values at knee height and pre-tasseling stage of maize as influenced by tillage treatments and nutrient management practices.

	NDVI Values at knee height stage (33 DAS)		NDVI Values at pre-tasseling (55 DAS)	
	2022	2023	2022	2023
Main plot: Tillage Treatments				
Zero Tillage	0.787	0.741	0.810	0.785
Conventional Tillage	0.711	0.698	0.777	0.764
Permanent Bed	0.730	0.710	0.782	0.762
Permanent Ridge	0.724	0.700	0.786	0.765
conventional tillage + Chisel plough	0.792	0.739	0.811	0.785
Minimum Tillage	0.753	0.719	0.803	0.773
SEm±	0.005	0.008	0.006	0.005
CD (p=0.05)	0.017	0.026	0.020	0.015
Sub plot: Nutrient management				
Green seeker guided Nitrogen application	0.746	0.725	0.807	0.777
SSNM (130:33:66 kg N:P ₂ O ₅ :K ₂ O)	0.751	0.716	0.788	0.770
100% RDN (120:60:40kg N:P ₂ O ₅ :K ₂ O)	0.752	0.712	0.789	0.770
SEm±	0.007	0.005	0.004	0.004
CD (p=0.05)	NS	NS	NS	NS

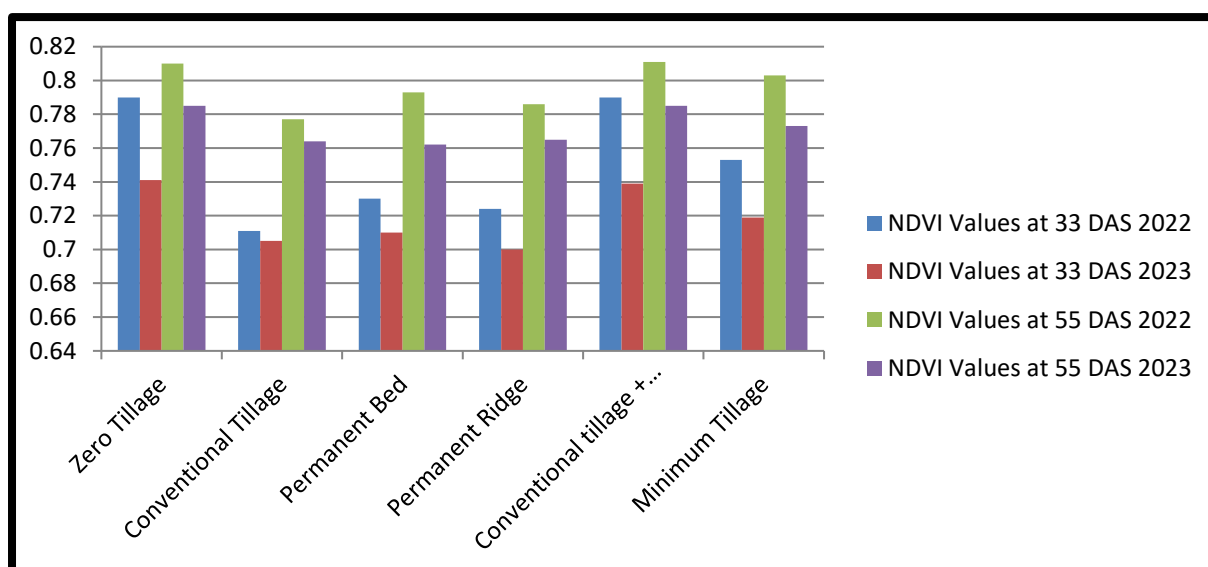


Fig. 2. Influence of tillage treatments on NDVI value at knee height stage (33 DAS) and pre tasseling stage (55 DAS)

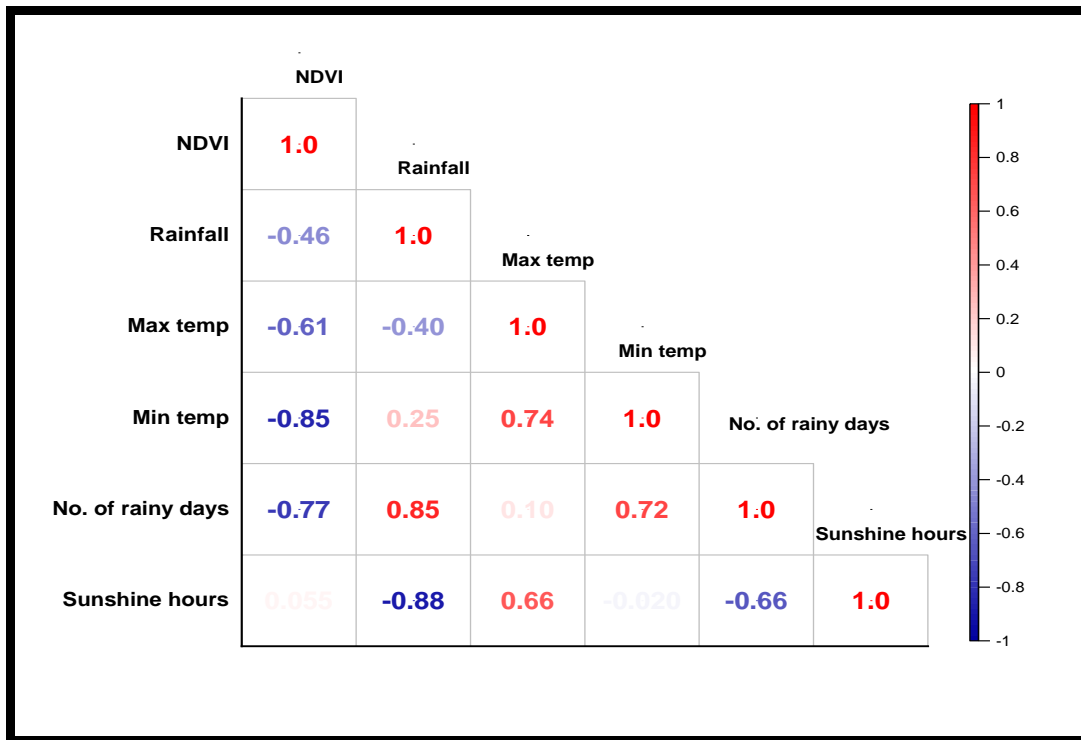


Fig. 3. Correlation between NDVI of maize crop and weather parameters (Rainfall, maximum temperature, minimum temperatures, number of rainy days and sunshine hours)

The observed negative correlation between the NDVI and various weather parameters, such as temperature and rainfall provides valuable insights into the complex interactions between environmental conditions and maize crop health. When NDVI values of maize crop decrease in response to adverse weather conditions, such as excessive rainfall, it suggests that these factors are detrimental to maize growth and vitality. The study is in line with the fact that health of *kharif* maize is hampered by the negative impact of heavy rainfall and more number of rainy days experienced by the crop due to heavy monsoon rains in months of July and August in Indo-gangetic plains.

The NDVI values in the second year of study were lower as compared to that observed in first year attributing to the impact of amount, intensity and duration of rainfall on crop growth [17], temperature and number of rainy days. Meteorological data recorded during experimentation period revealed that early and mid *kharif* season of 2023 experienced the heavy rainfall which was 603.6 mm in July and 395.2 mm in August as against 174.8 mm and 182.1 mm in July and August 2022, respectively. Thus in 2023 rainfall was higher by 428.8 mm in July and 213.1 mm in August than that of in 2022.

Incessant rain delayed sowing of crop, reduced sunlight availability to crop and enhanced nutrient leaching, in July 2023. Besides caused excess soil moisture for longer period and created anaerobic condition in root zone [18]. This enhanced soil water during vegetative stage most likely influenced plant NDVI [19]. All these factors together hampered crop growth in 2023 and were the main reasons that NDVI values in second years of experimentation were lower as compared to first year.

Optimization of agricultural practices, particularly tillage and nutrient management in response to weather forecast can avoid excessive moisture stress, ensure crop health, nutrient availability and thereby sustained yield levels. The zero tillage and conventional tillage + chisel plough consistently showed high NDVI values than conventional tillage indicating their effectiveness in countering excess moisture stress as compared to conventional tillage. Thus the study confirms that zero tillage, or conventional tillage + chisel maintain crop health even under heavy rainfall.

Moreover, the relationship between crop NDVI and weather parameters offer a profound understanding of crop-environment interactions,

providing a foundation for advancing productivity and sustainability in the face of changing climatic conditions.

4. CONCLUSION

In summary, the study provides valuable insights into the impact of various tillage practices and nutrient management strategies on the health of maize crops assessed through NDVI. Overall, the study highlights the importance of selecting tillage practices that can impact crop growth and development under adverse weather conditions. The zero tillage and conventional tillage + chisel plough consistently showed high NDVI values, indicating their effectiveness in promoting vegetative growth. In terms of nutrient management, all tested strategies provided similar benefits to the crop, suggesting their adaptability to sustain vegetative growth. The negative correlation between NDVI and weather parameters offers a deeper understanding of how environmental factors influence crop health. These insights are crucial for optimizing tillage and nutrient management to improve crop yield and sustainability under varied weather conditions.

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 writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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