Review Article

Influence of Tillage and Nutrient Management on Growth and Yield of Maize: A Review

ABSTRACT

Tillage practices significantly influence maize growth, yield, and soil health by altering the physical, chemical, and biological properties of soil. Conventional tillage generally enhances plant height, dry matter accumulation, and leaf area index, with notable benefits for grain yield and biomass production. In contrast, reduced and zero tillage systems improve soil conservation and promote stable production. Ridge and raised bed planting methods often outperform conventional and zero tillage, offering higher yields and better resource use efficiency. Permanent bed planting with residue retention further optimizes maize productivity by improving soil structure and nutrient cycling. Site-Specific Nutrient Management (SSNM) emerges as a vital approach to address nutrient imbalances and enhance fertilizer use efficiency. By tailoring nutrient applications to crop-specific and site-specific needs, SSNM significantly boosts maize growth and yield attributes, including cob length, grain weight, and biological yield. Studies reveal that SSNM outperforms conventional fertilization techniques by improving nutrient recovery rates, reducing environmental impacts, and maximizing economic returns. This review highlights the synergistic effect of tillage and SSNM on maize performance, emphasizing the need for integrated management practices to achieve sustainable agricultural productivity in diverse agro-ecological systems. The findings underscore the potential of these approaches to bridge yield gaps and support resilient cropping systems.

Keywords: Maize, Tillage, SSNM, Yield

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1. INTRODUCTION

South Asia's recent population surge, particularly in India, has heightened demand for food, fiber, and fodder, with the global reliance on staple cereals like rice, wheat, and maize. While India's crop production has tripled since 1965, food security faces threats from stagnant yields and climate change. The population, projected to reach 9 billion by 2050, further exacerbates these challenges, straining agriculture already burdened by resource-intensive practices, soil degradation, water scarcity, and climate-induced adversities (Farooq et al., 2022). Addressing these issues requires sustainable innovations like conservation agriculture, precision farming, and crop diversification. Maize (*Zea mays* L.), termed the "miracle crop" for its adaptability and high genetic potential, plays a pivotal role in Indian agriculture. As the fourth-largest maize producer globally, India dedicates 10.4 million ha to maize cultivation, yielding 33.2 million tonnes annually. In West Bengal, as per the report released by Agricultural Statistics at a Glance, 2022 maize contributes 3.68% to national production with a yield of 7158 kg ha^{-1}. Used for food, feed, starch, and industrial alcohol, maize demand is predicted to rise to 55 million tonnes by 2030, driven by poultry, pharmaceutical, and biofuel industries. Sustainable practices like conservation agriculture emphasize minimal tillage, permanent soil cover, and crop rotations to improve soil health, resource use efficiency, and reduce greenhouse gas emissions.

Conservation Agriculture enhances soil organic carbon, moisture retention, and nutrient efficiency, proving socioeconomically and environmentally beneficial (Anil *et al.*, 2022). Site-specific nutrient management (SSNM) complements conservation agriculture by optimizing nutrient use through field-specific recommendations based on soil and crop needs (Chen *et al.*, 2021). Tools like the Nutrient Expert® software assist in tailoring fertilizer applications, improving yields, and minimizing environmental impact (Pooniya *et al.*, 2021). SSNM's 4R principle (right source, dose, technique, and time) ensures efficient nutrient use, enhancing maize productivity, soil health, and profitability. Integrating conservation agriculture with SSNM and advanced decision-support tools offers sustainable solutions to India's agricultural challenges, balancing productivity, environmental conservation, and economic viability. These practices are crucial for meeting the growing food demand while preserving natural resources for future generations.

2.1 EFFECT OF TILLAGE PRACTICES ON GROWTH PARAMETERS

Studies have shown that reduced and direct tillage systems result in decreased maize plant height compared to conventional tillage, as reported by Blecharczyk *et al*. (2004). Khurshid *et al*. (2006) observed that tillage methods significantly influenced growth, with the highest plant height (214.94 cm) recorded under conventional tillage. Fernandes *et al*. (2007) emphasized that soil management practices, including conventional tillage, chisel ploughing + levelling disk, and no-tillage systems, help conserve the soil's physical, chemical, and biological properties, promoting better plant growth. Saha *et al*. (2010) reported that tillage treatments significantly increased plant height, while residue retention showed no significant effect in the initial years, as noted by Najafinezhad *et al*. (2007). The differences in maize plant height under various tillage systems are attributed to soil structure, moisture availability, and root development. Conventional tillage improves aeration, root penetration, and nutrient availability, leading to taller plants. Zero and reduced tillage may limit root expansion due to compacted soil layers, reducing nutrient uptake and water infiltration. Residue retention affects soil temperature and moisture but may not immediately impact plant height. Variations in tillage-induced soil properties influence maize growth dynamics across different systems (Bimbraw 2016; Kassam *et al*., 2022). Singh *et al*. (2011) recorded the tallest maize plants under fresh raised beds (212 cm) compared to permanent beds with residue (211.7 cm), conventional tillage (210.0 cm), zero tillage with residue (210.0 cm), and zero tillage without residue (195.0 cm). Similarly, Singh *et al*. (2009) reported the tallest maize plants under zero tillage on permanent beds, followed by zero till flat, zero till bed without residue, and conventional tillage.

Ram *et al*. (2010) found that plant height, dry matter accumulation, and leaf area index under different conventional and zero-till practices were statistically at par. Akbarnia *et al*. (2010) noted that reduced tillage resulted in the highest dry mass compared to conventional and no-tillage practices. Kumar and Kumar (2018) reported that maize exhibited the highest leaf area index under permanent bed tillage compared to conventional tillage. Zero tillage practices were found to achieve stable production comparable to conventional tillage, with enhanced shoot growth in maize (De and Bandyopadhya, 2013). Kutu (2012) observed significantly higher plant height in conventional tillage over zero tillage and minimum tillage, while the number of leaves per plant was higher in minimum tillage, which was at par with conventional tillage. Khan *et al*. (2009) reported significantly taller maize plants (221 cm) under minimum tillage compared to conventional and deep tillage. Conventional tillage showed a significantly higher leaf area index (3.07) compared to minimum and deep tillage.

Parihar *et al*. (2015) recorded the highest plant height, dry matter accumulation, and leaf area index under zero tillage with residue compared to other tillage methods, including conventional tillage with and without residue and permanent beds. Singh *et al*. (2018) highlighted the superiority of bed planting in terms of biomass production and grain yield over zero tillage and conventional tillage. Wasaya *et al*. (2012) observed that conventional tillage (2 cultivations), tillage with moldboard plough + 2 cultivations, and tillage with chisel plough + 2 cultivations resulted in high plant height, leaf area index, and dry matter accumulation. Memon *et al*. (2013) found that deep tillage produced the tallest plants with more leaves than conventional and zero tillage. Ita *et al*. (2014) reported a significant difference in plant height, with zero tillage and glyphosate application resulting in taller plants (1.89 m) compared to conventional tillage with hand weeding (1.69 m). Javeed *et al*. (2014) noted greater dry matter and crop growth rates in zero tillage sown crops than in conventional and deep tillage.

Khan *et al*. (2014) observed the highest dry matter accumulation in conventional tillage, with a 4% increase in minimum tillage after anthesis compared to deep tillage. Agber *et al*. (2017) reported significantly higher plant height and leaf area under ridged tillage than no tillage, minimum tillage, and flatbed tillage. Khan *et al*. (2008) found that minimum tillage and conventional tillage resulted in higher leaf area and leaf area index. Aikins *et al*. (2012) observed that disc harrowing produced higher plant height, leaf area index, and number of leaves per plant compared to no-tillage practices, with the least values recorded under conventional tillage (ploughing and harrowing). You *et al*. (2017) found that short-term reduced tillage, such as no-tillage and rotary tillage, promoted shoot biomass compared to plough tillage. Saha *et al*. (2023) reported higher values for plant height, dry matter accumulation, leaf area index, and crop growth rate under permanent beds with residue compared to no residue in both zero-

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tillage and conventional tillage practices. The variations in plant height, dry matter accumulation, and leaf area index under different tillage systems arise due to differences in soil structure, moisture retention, and nutrient availability. Conventional tillage improves aeration and root penetration, enhancing early growth, while reduced and zero tillage conserve soil moisture and organic matter, supporting stable biomass production. Minimum tillage often balances these effects, promoting optimal leaf expansion. Permanent bed tillage likely benefits maize by maintaining favorable soil conditions for root and shoot growth (Page *et al*., 2019).

2.2 EFFECT OF TILLAGE PRACTICES ON YIELD AND YIELD PARAMETERS

Maize demonstrates exceptional adaptability to various soils and climatic conditions, making it suitable for diverse cropping systems in India. Tillage and mulching practices greatly influence critical yield attributes, such as cob length, cob girth, grains per cob, grain yield, and stover yield. Khan *et al*. (2008) observed that both minimum and conventional tillage resulted in a greater number of grains per cob, 1000-grain weight, and biological yield compared to deep tillage. Ridge planting notably produced a higher number of cobs per plant, increased grain quantity, and improved biological yield (Bakht *et al*., 2006). Ridge and furrow systems were found to enhance grain and stover yields by 18% and 10.1%, respectively, compared to zero tillage, while raised beds showed yield increases of 14.5% and 8.6% (Choudhury *et al*., 2013).

Research by Sepat & Rana (2013) found no significant differences in the 1000-grain weight of maize across various tillage systems, including permanent beds with residue, zero till flats with residue, and fresh beds with residue. In one study, conventional tillage recorded the highest mean grain yield (2183 kg ha^{-1}), whereas no-till systems had the lowest mean yield (1286 kg ha^{-1}) (Sharma *et al*., 2010). Zero tillage, however, increased grain yield by reducing weed population and dry weight compared to no tillage (Sharma & Gautam, 2010). Permanent bed planting increased maize and cotton yields by 8% and 24%, respectively, compared to conventional bed planting (Hakim *et al*., 2011). Videnovic *et al*. (2011) reported that conventional tillage outperformed both reduced and no-tillage systems in maize yield. Yadav *et al*. (2015) showed that conventional tillage with raised beds resulted in the longest and thickest cobs, along with the highest grain row count per cob, compared to other tillage practices.

Thierfelder *et al*. (2015) documented a 24–40% maize yield increase over time with no-tillage and residue retention versus conventional systems. Ramesh *et al*. (2016) found no significant differences in green cob, green fodder, biological yield, and harvest index across various tillage systems. Parihar *et al*. (2016) reported that zero tillage provided maximum yield attributes for maize, though wheat performed better on permanent beds in initial years. Li *et al*. (2015) demonstrated that conservation tillage improved soil properties, leading to better crop yields. Additionally, Parihar *et al*. (2018) observed higher yield attributes (cobs per m^2, cob length, and grains per cob) in zero tillage than in conventional tillage. The observed variations in maize yield and yield attributes across different tillage systems can be attributed to their effects on soil structure, moisture retention, nutrient availability, and weed suppression. Conventional tillage often enhances root penetration, aeration, and nutrient mineralization, leading to better growth and yield. Ridge and furrow planting, along with raised beds, improve soil drainage, aeration, and root-zone moisture, thereby increasing grain and stover yield. Zero tillage with residue retention enhances soil organic matter, microbial activity, and moisture conservation, contributing to long-term yield stability. Deep tillage, despite loosening soil, may disrupt soil aggregates and deplete soil moisture, reducing yield. Conservation tillage systems improve soil health and nutrient cycling, leading to better crop performance over time (Parihar *et al*., 2017; Sadiq *et al*., 2024)

Singha *et al*. (2018) reported that bed planting improved grain yield by 13–16.9% compared to conventional and zero tillage. Similarly, Basavanneppa *et al*. (2017) found bed planting superior to conventional and zero-tillage practices. Nwite *et al*. (2017) noted that deep tillage produced significantly higher grain yield and harvest index than zero and shallow tillage. Khan *et al*. (2014) recorded the highest harvest index (18.73%) in conventional tillage, which was 2.93% greater than deep tillage. Kumar *et al*. (2018) identified improved yield attributes, including cob count, cob length, grain weight, and yield under bed planting. Aditi *et al*. (2019) found no significant yield differences between zero and conventional tillage, while permanent bed planting and strip tillage resulted in higher yields than conventional tillage. Omara *et al*. (2019) showed higher wheat yields under no-tillage compared to conventional tillage, and found that deep and conventional tillage provided better yield attributes and biomass than reduced tillage. Hasnain *et al*. (2021) documented higher grain yield and protein content in maize under permanent raised beds compared to conventional tillage systems.

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2.3 EFFECT OF NUTRIENT MANAGEMENT PRACTICES ON GROWTH PARAMETERS

Sapkota *et al*. (2021) identified SSNM as a sustainable approach that optimizes fertilizer management to meet the nutritional demands of crops, including maize. Plant height, a critical growth parameter, is directly linked to the productive potential of plants in terms of grain yield. Optimal plant height is positively correlated with productivity (Zhang *et al*., 2017; Lan *et al*., 2023). Ren (2022) also reported a positive correlation between plant height and grain yield, with taller plants yielding better. Asghar *et al*. (2010) found that plant height increased linearly with NPK application, with the maximum plant height (198.55 cm) achieved at 250-110-85 kg NPK ha^{-1}, compared to the minimum (143.60 cm) observed in the control. Similar results were reported by Ekwere *et al*. (2013). Rehman *et al*. (2010) recorded the tallest plants (216.5 cm) with a full nitrogen dose of 250 kg ha^{-1}, while the shortest (184.5 cm) were observed with no fertilizer.

Studies by Ibrahim *et al*. (2022) and Muhammad *et al*. (2022) also confirmed increased plant height with higher nitrogen rates. Reddy *et al*. (2019) reported a maximum plant height of 160 cm at 150 kg ha^{-1} nitrogen application, significantly higher than the 90 cm observed at 90 kg ha^{-1}. Roshini *et al*. (2022) observed an increase in maize plant height from 130 cm to 193 cm as nitrogen application rose from 0 to 240 kg ha^{-1}. Govindasamy *et al*. (2023) similarly documented an increase from 190 cm to 201 cm with nitrogen levels increasing from 60 to 180 kg ha^{-1}. Sivamurugan *et al*. (2017), in a kharif experiment at Coimbatore, reported that RDF (250:75:75 NPK kg ha^{-1}) resulted in the tallest plants, on par with STCR (232:99:37.5 NPK kg ha^{-1}) and superior to SSNM (110:61:90 NPK kg ha^{-1}), likely due to prolonged vegetative growth.

Walter *et al*. (2017) observed that site-specific nitrogen management resulted in a higher leaf area than conventional and control treatments. Nitrogen fertilizer also significantly affects maize leaf area (Tofa *et al*., 2022). Berdjour *et al*. (2020) recorded the highest number of leaves (32.10), leaf area per plant (1600 cm^2), and leaf area index (0.853) with 600 kg NPK ha^{-1}, 120% higher than the control. Szabo *et al*. (2022) reported maximum total leaf area (4161.5 cm^2) and leaf area index (2.22) at 300 kg NPK ha^{-1} compared to lower rates (0, 150, 200, and 250 kg NPK ha^{-1}). Obidiebube *et al*. (2012) found the highest total leaf area (5489 cm^2) in plants fertilized with 0.15 kg NPK ha^{-1} (15:15:15), followed by 0.10 kg NPK ha^{-1} (5321 cm^2), with the lowest (4221 cm^2) in unfertilized plants. Nitrogen is a key macronutrient essential for chlorophyll synthesis, protein formation, and enzymatic activity, all of which drive photosynthesis and biomass accumulation. Increased nitrogen availability promotes cell division and elongation, leading to greater plant height and higher dry matter accumulation. Optimal nutrient application enhances root development, improving water and nutrient uptake, which further supports vegetative growth. The positive correlation between plant height and grain yield can be attributed to improved light interception, greater leaf area, and efficient carbon assimilation. Higher nitrogen levels also increase leaf area index, which maximizes photosynthesis and dry matter production. SSNM, by matching nutrient supply with crop demand, ensures efficient nutrient utilization, minimizing losses and improving growth parameters. Additionally, balanced fertilization, including phosphorus and potassium, supports root proliferation and metabolic processes, further enhancing maize productivity (Zayed *et al*., 2023).

Ogbomo and Ogbomo (2009) demonstrated that maize dry matter production was 11.76%, 19.49%, and 115% higher at 600 kg NPK ha^{-1} than at 400, 200, and 0 kg NPK ha^{-1}, respectively. Kumar *et al*. (2014) found significant improvements in growth parameters, including crop growth rate and relative growth rate, with SSNM over RDF. SSNM significantly enhanced dry matter accumulation at various growth stages (Kumar *et al*., 2014). Singh *et al*. (2012) concluded that increasing nitrogen levels from 0 to 120 kg ha^{-1} significantly improved dry weight per plant, though 150 kg N ha^{-1} was on par with 120 kg N ha^{-1}. Meena *et al*. (2012) observed higher crop growth rates with nitrogen application up to 150 kg N ha^{-1}.

Chetan (2015) found that applying 367:143:226 kg ha^{-1} N:P_2O_5:K_2O through SSNM for a target yield of 10 t ha^{-1} resulted in greater plant height (215.45 cm and 216.14 cm) and leaf area index (4.31) at 90 DAS and harvest, compared to other techniques. Sinha (2016) reported significantly higher plant height, leaf area, dry matter accumulation, and crop growth rate with SSNM compared to RDF under conservation agriculture. Anand *et al*. (2017) recorded significantly taller plants (267.42 cm) and more leaves per plant (17.67) with SSNM for a 10 t ha^{-1} target yield, compared to state-recommended fertilizer. Pooniya *et al*. (2015) noted a significant increase in CGR across growth stages with SSNM, except during the 0–30 days period, where CGR was comparable to 100% RDF.

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2.4 EFFECT OF NUTRIENT MANAGEMENT PRACTICES ON YIELD AND YIELD PARAMETERS

Bakht *et al*. (2006) found that ridge planting combined with 200 kg nitrogen ha^{-1} resulted in the highest maize yields, improving grain production metrics such as the number of cobs and grains per cob. Similarly, Biradar *et al*. (2006) observed superior yields in rice, wheat, and chickpea under SSNM compared to conventional fertilization methods. Amanullah *et al*. (2009) reported optimal biological yields in maize with nitrogen applied in four to five split doses at a high plant density, with 180 kg nitrogen ha^{-1} producing the best results. Ahmad *et al*. (2009) demonstrated that conventional tillage and 120 kg nitrogen ha^{-1}, applied in two stages (pre-planting and post-planting), achieved the best maize yields.

Onasanya *et al*. (2009) noted significantly higher maize yields with a combination of 120 kg nitrogen ha^{-1} and 40 kg phosphorus ha^{-1} compared to other nutrient combinations. Murni *et al*. (2010) reported a 19% yield increase (1.5 mg ha^{-1}) in maize under SSNM, where nitrogen was the limiting nutrient, followed by phosphorus and potassium. Ghaffari *et al*. (2011) observed notable maize yield improvements by supplementing the recommended NPK dose with a single multi-nutrient spray, enhancing grain rows per cob, grains per cob, and 100-grain weight. Pampolino *et al*. (2012) highlighted that the Nutrient Expert for Hybrid Maize (NEHM) tool increased maize yields by 0.9 t ha^{-1} in Indonesia and 1.6 t ha^{-1} in the Philippines compared to conventional practices.

Jat *et al*. (2013) recorded significantly higher maize yields under SSNM across multiple regions, outperforming state recommendations. Kumar *et al*. (2014) corroborated these findings, reporting improved yield attributes, such as cob length, girth, and grain rows per cob, under SSNM compared to reduced and standard fertilizer doses. Sapkota *et al*. (2017) noted significantly enhanced maize grain yields with nitrogen applications up to 240 kg ha^{-1}. Zothanmawii *et al*. (2018) found that 180 kg nitrogen ha^{-1} improved cob length, girth, and grain weight. Pasuquin *et al*. (2014) observed a 13% maize yield increase under SSNM compared to farmer practices, and Kumar *et al*. (2015) reported similarly enhanced yields with SSNM over reduced and standard doses. Joshi *et al*. (2018) demonstrated that SSNM targeting a 10 t ha^{-1} yield produced the highest stover yield. Anand *et al*. (2017) noted that SSNM treatments yielded significantly more stover than conventional methods. Shahi *et al*. (2020) concluded that SSNM with 200:120:100 N:P:K in maize outperformed traditional practices (180:91:71 N:P:K), with yield reductions of 10–15% in plots lacking phosphorus or potassium and up to 80% reductions without nitrogen.

Jat *et al*. (2018) showed that SSNM improved maize grain yield, cob length, cob weight, and grain count per cob compared to farmer practices and recommended fertilizer doses. Meena *et al*. (2014) observed increased maize productivity and micronutrient uptake with SSNM in Udaipur, with 17–18% higher grain, stover, and biological yields than control treatments. Singh *et al*. (2020) demonstrated that nutrient expert-based SSNM increased maize grain yield over conventional doses and farmer practices, affirming SSNM's role in improving productivity across regions. Phillippi *et al*. (2018) reported significant yield gains in maize with nitrogen application based on the Nutrient Expert tool. Similarly, Sharma *et al*. (2019) found that 150 kg nitrogen ha^{-1} produced the highest maize grain yield compared to lower and higher nitrogen levels. Singh *et al*. (2015) highlighted a 38.1% maize yield increase with SSNM over farmer practices due to its efficient nutrient supply in line with crop demand.

SSNM's benefits extend beyond maize. Mohanta *et al*. (2021) reported yield improvements in rice using tools like the Green Seeker and Nutrient Expert, achieving 19.21% and 14.71% increases, respectively, over farmer practices. Shankar *et al*. (2021) observed increased rice yields with adequate nutrient supply, while Hasnain *et al*. (2021) found that combining the Nutrient Expert and Green Seeker tools outperformed standalone methods, improving grain yield, protein content, and protein yield. Shahi *et al*. (2020) emphasized the importance of optimized nutrient mixes (200:120:100 N:P:K) under SSNM, outperforming conventional methods and significantly reducing yields when nutrients were omitted, especially nitrogen (up to 80% reduction). Singh *et al*. (2015) confirmed similar benefits in Kanpur. Avinash *et al*. (2023) demonstrated that using a Leaf Colour Chart (LCC) nitrogen split along with nutrient expert recommendations increased rice yield by 80.37% compared to conventional practices, underscoring SSNM's potential for significant yield gains in various crops. The improved yields observed with SSNM are primarily due to its ability to optimize nutrient supply based on crop demand, soil conditions, and weather patterns. SSNM ensures that the right nutrients, especially nitrogen, phosphorus, and potassium, are applied in precise amounts at the appropriate stages of crop growth, promoting efficient nutrient uptake and enhancing plant growth. By using tools like the Nutrient Expert,

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SSNM facilitate fertilizer recommendations to specific site conditions, preventing over- or under-application. This targeted nutrient management improves key yield attributes such as cob length, grain count, and stover production. Additionally, SSNM's adaptive approach increases soil health and nutrient availability, leading to more consistent and higher crop yields compared to conventional fertilization methods, which often lack such precision and adaptability (Rodriguez, 2020; Khan *et al*., 2023).

3. CONCLUSION

In conclusion, the effect of tillage practices and nutrient management on maize growth, yield, and overall productivity is complex, with varying outcomes depending on soil conditions, tillage methods, and nutrient application strategies. Conventional tillage, while promoting better early growth through enhanced aeration and root penetration, may deplete soil moisture over time, affecting long-term yield stability. Zero tillage and Conservation Agriculture, on the other hand, offer significant environmental benefits by conserving soil moisture, improving organic matter, and enhancing microbial activity. However, these practices may initially lead to lower growth parameters compared to conventional tillage due to reduced soil disturbance. The integration of site-specific nutrient management with appropriate tillage systems has proven effective in optimizing nutrient use, improving maize growth, and enhancing yields. SSNM's tailored approach ensures that nutrient requirements are met while minimizing environmental impacts, thereby promoting sustainable agricultural practices. Combining conservation tillage and SSNM provides a balanced approach to addressing the challenges of soil degradation, water scarcity, and the need for increased agricultural productivity in the face of rising global demand. Such practices are essential for ensuring food security and long-term agricultural sustainability in regions like South Asia.

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 writing or editing of this manuscript.

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