Original Research Article

A comparative study of long-term conventional and no-tillage practices on the basis of available soil nutrients, soil organic carbon and crop productivityin black soils of central India

ABSTRACT

Crop residue removal in conventional tillage (CT) can cause the depletion of soil nutrients (such as N, P, K) and organic carbon resulting in negative nutrient balance/depleted soil fertility. No-tillage (NT) is seen as a good substitute for CT in terms of preserving soil fertility and enhancing the soil productivity. The present study carried out in black soil of central India comprising of 2 tillage systems and 3 crop rotations to compared the effects of long-term conventional and no-tillage practices on available soil nutrients, soil organic carbon and crop yield differences in different cropping systems. Conventional tillage and No-till were factored into, soybean-wheat, maize-wheat and maize-gram systems. The long-term no-tillage treatment resulted in higher soil organic carbon (0.95%), available soil nitrogen (222.61 Kgha^{-1}), phosphorus (24.62 Kg ha^{-1}) and potassium (583.63 Kg ha^{-1}) contents at the 0–10 cm depth than the conventional tillage treatment.Crop productivity in terms of soybean grain equivalent yield (SGEY)was significantly higher in NT (41.42quintal ha^{-1}) compare to CT (35.36 quintal ha^{-1}).The study proven that no-tillage is an effective strategy to improve soil fertility (organic carbon and available nutrients) and crop yield of different cropping systems in black soils of central India.

***Keywords* -** Conventional tillage, No-tillage, Available nutrients, Soil organic carbon, Crop productivity.

1.Introduction

"In order to check the degrading soil health and mitigate the negative impacts of climate change on soil and environment. The conservation agriculture (CA) is becoming popular worldwide due to its enhanced Carbon sequestration potential and favourable effects on soil fertility and nutrient dynamics"[1, 2]. "Conservation agriculture based on principles of no-tillage (NT), residue retention and crop diversification improve the physical, chemical and biological properties of the soil"[3]. "The main objective of conservation agriculture is to reverse the process of soil degradation and to conserve or improve available soil resources by improving soil structure and increasing soil organic matter.CA is a combination of environmental conservation and enhanced and sustained agricultural production and this balance is achieved through minimize soil disturbance, maintain soil cover, and promote crop diversity, all of which contribute to healthier soils and reduced environmental impact" [4]."The success of conservation agriculture technologies has been verified by their worldwide application over 125 million hectares andparticularlyprevalent in the Americas and Australia" [5].

"Tillage systems, apart from improving soil physical and biological health, are found to influence the chemical properties of soil and have a major impact on soil productivity and sustainability. Conventional tillage (CT) is a highly intensive plough-based tillage system that consume higher energy,where crop residues are completely removed, that disrupts the soil structure leads to soil erosion, decreases organic matter, and reduces soil fertility over time, ultimately resulting in soil degradation.The CT practices may harm long-term soil efficiency and crop production because of soil erosion and the loss of organic matter. Sustainable soil management can be practiced through conservation tillage (no-tillage), high crop residue return, and crop rotation"[3]. "No-tillage (NT) is becoming increasingly popular worldwide due toreduces the cost of cultivation compared to conventional tillage and improves soil chemical properties and crop productivity. Research conducted across different climatic conditions, soil types, and crop rotation systems revealed that soils under reduced tillage(RT) and no-tillage have significantly higher soil organic matter contents than soils tilled by conventional tillage"[6]. "The advantages of no-tillage practices over conventional tillage include (1) reducing cultivation cost; (2) building up soil organic matter (organic C and organic N),(3) increase microbial biomass (4) conserving soil moisture"[7, 8, 9]."Tillage practices have an impact on the availability and storage of soil nitrogen, which may have an impact on crop yield and quality. Several studies have shown that conservation tillage, such as NT, usually increases soil N content compared to conventional tillage under dryland agriculture"[10, 11].

"Crop residue removal in CT can cause the depletion of soil nutrients (such as N, P, K) and may result in ne

"Therefore, it is important to understand nutrient distribution under different tillage regimes, cropping systems and ultimately crop yields. Agronomists and scientists generally agree that no-tillage (NT) is a good substitute for conventional tillage (CT) in terms of preserving natural resources and enhancing the soil ecosystem. In addition to its ecological and economic benefits for soil management, NT has a greater potential than CT to improve soil physicochemical properties, soil organic carbon, and crop yield”[13, 14].

The Vertisols having high clay content prone to high risk of soil erosion, higher losses of soil moisture due to deeper cracks, and carbon losses by oxidation due to higher temperature and self-ploughing. Hence these soils need the technologies which may give an intensive care and physical protection to soil, water, nutrient, and organic carbon. The area covered by black soil (Vertisols) in India is 70.3 m hectares, or 22% of the country's total land area, of which 34.2 and 30.2% are in the central Indian states of Maharashtra and Madhya Pradesh. Hence, main objective of the study presented in this paper was to evaluate the long-term effects of ideal tillage technology (NT) against the conventional one (CT) on the soil health and crop productivity in the black soils of central India.

2. Method and material

2.1. Discerption of experiment

The study was carried out in black soil of central India(23°18′N, 77°24′E, and 485 meters above sea level) in the cropping season of 2023as a part of original long-term experiment on conservation agriculture. The originalexperiment was established in June 2010 at ICAR-Indian Institute of Soil Science, Bhopal in a randomized block design in 2 (tillage system) x 3 (crop rotation) factorial arrangement. Conventional tillage and No-till were factored into, soybean-wheat, maize-wheat and maize-gram systems. Each treatment was replicated 4 times on 10 x 10 m^2 plots.Hot sub-humid type of climate prevails in the study area with annual mean air temperature, mean annual rainfall, and potential evapotranspiration of 25 ^oC, 1130 mm and 1400 mm, respectively.Monthly weather data for the experimental period is presented in table 1.The soil of the experimental site is classified as a Typic Haplustert containing 58% clay, 22% silt and 20% sand in the top 0-15 cm layer.Soil samples were collected in April 2024, following winter (rabi) crop harvestfromthreedepths(0-10,10-20 and 20-30 cm) of each plot. The soil of 2 mm size used for analysis of soil available nutrients (N, P and K) and for soil organic carbon estimation we used 0.5 mm size of soil.

2.2. Tillage systems

- **Conventional tillage (CT)/Farmers practices:** Three to four tillage operations using duck foot cultivator or sweep tillage/planting residue removal during *Kharif* and one sweep tillage followed by planting during *Rabi* season.

- **No-Tillage (NT) with residue retention:** No tillage, direct sowing during *Kharif* and *Rabi* season using Happy seeder/no-till seed drill and residue retained (30 cm height) on the field.Applying pre-emergent or post-emergent herbicides used to manage weeds effectively.

Table 1.Monthly weather data during crop season

Monthly weather data during crop season					
Months	**Average air temperature (°C)**		**Total Pan Evaporation (mm)**	**Total Rainfall (mm)**	**Rainy days**
	Minimum	**Maximum**			
2023					
June	26.08	35.81	227.70	139.50	8
July	25.02	31.58	104.90	277.50	17
August	23.44	30.32	100.80	84.80	6
September	23.87	30.96	89.00	300.60	14
October	19.28	33.10	129.60	0.00	0
November	13.93	29.43	93.80	12.00	2
December	11.74	25.59	69.50	20.20	2
2024					
January	10.3	23.9	62.7	11.9	2
February	12.8	27.6	87.1	53.2	5
March	16.1	33.4	157.2	5.8	0
April	21.9	37.0	198.9	82.3	6
May	25.5	41.0	261.5	5.8	0

List 1: Treatment details

Treatment details	
T_1	Soybean-Wheat Cropping sequence in Conventional tillage with residues removed
T_2	Maize-Wheat Cropping sequence in Conventional tillage with residues removed
T_3	Maize-Gram Cropping sequence in Conventional tillage with residues removed
T_4	Maize-Gram Cropping sequence in No- tillage with residuesretained
T_5	Maize-Wheat Cropping sequence in No- tillage with residuesretained
T_6	Soybean-Wheat Cropping sequence in No- tillage with residuesretained

2.3. Analytical methods

Chemical properties of soil

Organic carbon content of the soil sample was determined using following Walkley and Black wet digestion method [15]. Available nitrogen content insoil was determined by the alkaline potassium permanganate method as described by Subbiah and Asija (1956) [16]. The available phosphorus content in soil was estimated by extraction procedure as described by Olsen's *et al.* (1954) [17]and colour developed was done by ascorbic acid method. The available potassium content in soil was extracted with neutral normal ammonium acetate and estimated by using Flame photometer as described by Jakson (1973) [17].

Soybean grain equivalent yield (SGEY)

For comparative performance of different cropping sequences under different tillage practices, yield of all crops was converted into SGEY (quintalha^{-1}) by considering minimum support price (MSP) in Indian Rupees (INR)of 2023 (soybean- 4600 INR quintal^{-1}, maize-2090 INR quintal^{-1}, gram- 5335 INR quintal^{-1}, wheat- 2025 INR quintal^{-1}) as fixed by the government in Indian Rupees (INR) quintal^{-1}.

For example, for maize yield conversion–

$$\textbf{SGEY of Maize} = \frac{\textbf{Yield of Maize grain x MSP of Maize}}{\textbf{Soybean grain price (MSP)}}$$

Statistical analysis

All data recorded for different soil properties were analysed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) [19] for factorial RBD.The significant differences among the treatments were calculated at 5% probability levels (P= 0.05).

3. Result and Discussion

3.1. Long-term effects of conventional and no-tillage on soil organic carbon

Soil organic carbon (SOC) is significantly higher in NT (0.95%) than CT (0.85%) in 0–10 cm depth only (Table 2 and Fig. 1). The SOC concentration is 11.76% higher in NT than CT. Cropping systems and the interaction of tillage and cropping systems also affect SOC in the upper 10 cm depth of the soil. Maize-Wheat cropping system in NT has a higher SOC than other cropping system. Value of SOC decreased with increase in depth. These results are in accordance with Gonzalez-Sanchez *et al.* (2012) [20], who reported that zero-tillage practices sequester more organic carbon in the soil as compared to conventional tillage. The increase in SOC concentration at 0–10 cm soil depth in the NT system compared with the CT system could be due to surface retention of crop residues and a lower rate of organic matter decomposition due to minimum soil disturbance [21]. At lower soil depth (10-20 and 20-30 cm), although the SOC is less (than top layer), but in general NT treatment have high SOC content than CT.

3.2. Long-term effect of conventional and no-tillage on available nutrients in the soil

No-tillage has recorded a higher concentration of available nitrogen (4.14%), phosphorus (10.4%) and potassium (3.48%) in the upper surface (0–10 cm) of soil than CT (Table 2 and Fig. 2, 3, 4). Machraoui *et al.* (2010) [9] and Kumawat *et al.* (2022) [22] also observed that the nutrient (N, P and K) contents were higher under no-tillage than conventional tillage in surface soil. Available nitrogen (222.61 kg $ha^{-1)}$, phosphorus (24.62 kg ha^{-1}), and potassium (583.39 kg ha^{-1}) are significantly higher in NT than CT plots. Potassium is also affected by the cropping system. “The soybean-wheat system has higher available K than other cropping systems in both NT and CT plots. The beneficial effect of CA in terms of higher nutrient availability may be due to crop residue retention over the soil surface, arresting their leaching losses by reducing the decomposition of surface residues, and the larger nutrient mineralization potential of the soil as compared to CT”[23].“The increase of nutrients such as N, P, K, in the soil under NT practice is beneficial to soil chemical and physical properties and crop production and yield in the long-term” [9].“The higher concentration of available phosphorus (P) in CA practices is due to higher organic matter and conversion of organic P present in it into available P because CA practices promote the activity of soil microorganisms, which help to convert organic phosphorus into inorganic forms that are more readily available to plants”.[24].Higher available potassium (K) might be attributed to additions of a large amount of K through crop residues as crop residues contain high concentrations of total K, which is decompose through microbial action and organic potassium in crop residues is converted into inorganic (available) forms, primarily potassium ions (K^+) [25]. The higher K content in soil under soybean-wheat cropping system could also be due to relatively less removal of K by soybean compared to maize crop in maize based-cropping systems.

Table 2. Long-term impact of conventional and no-tillage practises on soil organic carbon and available nitrogen, phosphorus, potassium in soil

		Soil organic carbon (%)			Nitrogen (Kg ha^{-1})			Phosphorus (Kg ha^{-1})			Potassium (Kg ha^{-1})		
Tillage System	**Cropping System**	**0-10 cm**	**10-20 cm**	**20-30 cm**	**0-10 cm**	**10-20 cm**	**20-30 cm**	**0-10 cm**	**10-20 cm**	**20-30 cm**	**0-10 cm**	**10-20 cm**	**20-30 cm**
CT	Soybean-Wheat	0.85	0.73	0.60	213.70	173.13	159.40	22.24	11.89	5.57	580.7	425.9	413.36
	Maize-Wheat	0.83	0.69	0.63	212.20	181.30	161.21	23.76	10.34	4.5	570.55	418.36	407.46
	Maize -Gram	0.78	0.72	0.64	215.34	180.40	151.11	20.91	11.5	5.2	539.98	407.94	401.56
	Mean	**0.82**	**0.72**	**0.62**	**213.75**	**178.28**	**157.24**	**22.3**	**11.24**	**5.09**	**563.75**	**417.4**	**407.46**
NT	Soybean-Wheat	0.86	0.7	0.65	213.19	175.62	160.46	25.43	10.03	4.81	591.66	415.48	404.02
	Maize-Wheat	1.01	0.74	0.62	223.67	176.62	159.26	23.78	10.03	4.19	583.52	407.39	399.54
	Maize -Gram	0.99	0.73	0.65	230.97	168.94	158.91	24.65	11.43	5.28	575	405.81	404.62
	Mean	**0.95**	**0.72**	**0.64**	**222.61**	**173.72**	**159.54**	**24.62**	**10.49**	**4.76**	**583.39**	**409.56**	**402.73**
CD	TS	0.04*	NS	NS	7.37*	NS	NS	2.29*	NS	NS	18.34*	NS	NS
(*P*= 0.05)	CS	0.05*	NS	NS	NS	NS	NS	NS	NS	NS	22.46*	NS	NS
	TS X CS	0.07*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

CT- Conventional tillage, NT- No-tillage, TS- Tillage system, CS- Cropping system, *- Significance result, NS- Not significance result

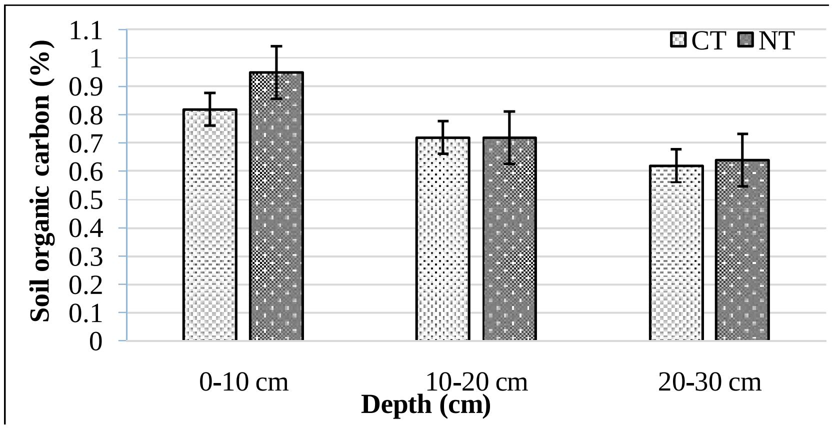

Fig.1 Long-term impact of conventional and no-tillage practises on soil organic carbon (SOC%), Error bars represent standard error

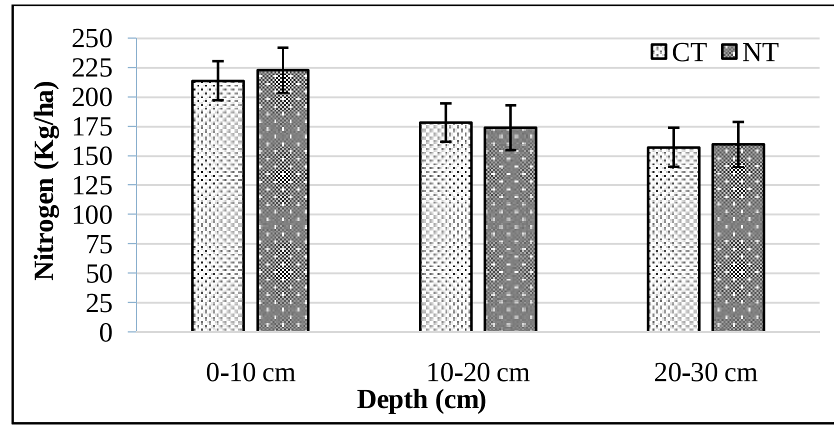

Fig.2 Long-term impact of conventional and no-tillage practises on available nitrogen (Kg ha^{-1}), Error bars represent standard error

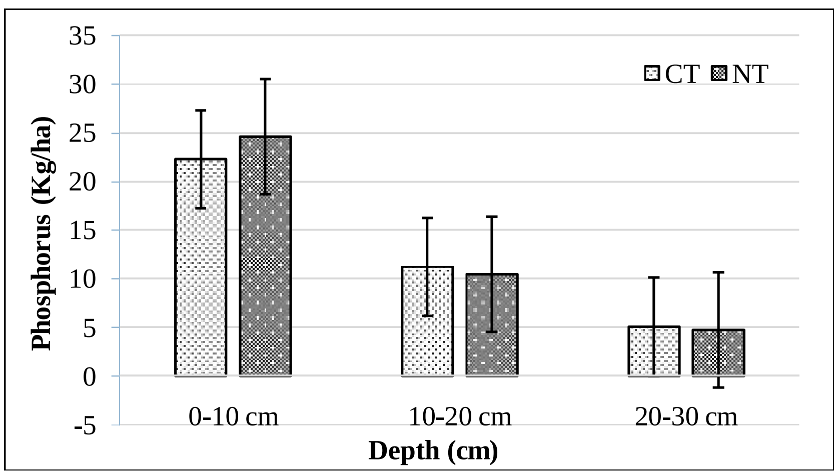

Fig.3 Long-term impact of conventional and no-tillage practises on available phosphorus (Kg ha^{-1}), Error bars represent standard error

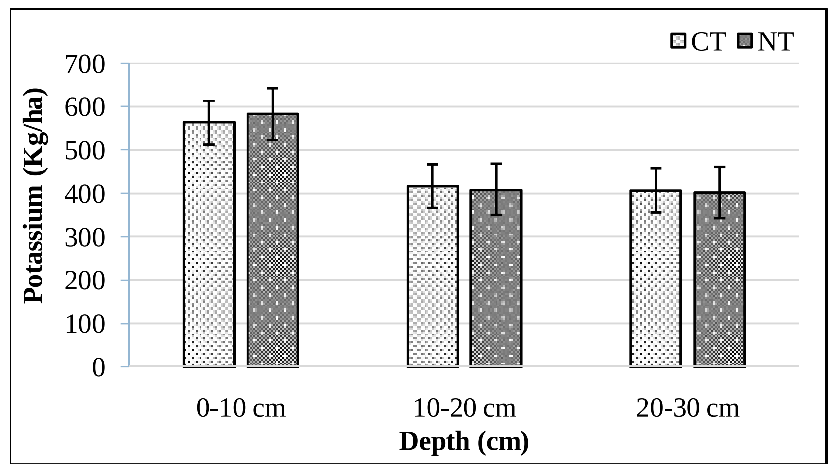

Fig.4 Long-term impact of conventional and no-tillage practises on available potassium (Kg ha^{-1}), Error bars represent standard error

3.3. Long-term effects of conventional and no-tillage on crop productivity

The grain yield of the crops (Maize, Soybean, Wheat, Gram) was found to be higher in NT with residue retention plots than conventionally tilled plots with residue removed(Table 3), but the biological yield of the different crops was found to be statistically similar between the NT plots and the CT plots. Crop yield in terms of soybean grain equivalent yield (SGEY) is significantly higher in NT (41.42 quintal ha^{-1}) than CT (35.36 quintal ha^{-1}). Maize-gram cropping system has the highest SGEY followed by maize-wheat cropping systems compared to soybean-wheat cropping system. (Table 3). Singh *et al.* (2005) [26] also concluded that the highest soybean grain yield of 36.6 q ha^{-1} was obtained in zero tillage than conventional tillage (34.1 q ha^{-1}). Improvements in soil fertility and soil water storage, reductions in pests/diseases and moderated soil temperatures due to residue retention in NT can help improve plant growth and yield [27].Hunag *et al.* (2008) [28] also concluded that crop grown with no-tillage showed increased nutrient performance, which improved the flow of water in plants and boost crop yield.

Table 3. Long-term impact of conventional and no-tillage practises on Soybean grain equivalent yield (quintal ha^{-1}) of different cropping systems

Soybean grain equivalent yield (SGEY) quintal ha^{-1}				
Tillage System	**Cropping System**	***Kharif***	***Rabi***	***Kharif* + *Rabi***
CT	Soybean-Wheat	7.90	14.32	22.22
	Maize-Wheat	24.95	14.99	39.94
	Maize -Gram	23.22	19.93	43.91
	Mean	**18.69**	**16.41**	**35.36**
NT	Soybean-Wheat	9.51	16.45	25.64
	Maize-Wheat	27.46	15.91	43.36
	Maize -Gram	29.04	26.21	55.25
	Mean	**22.00**	**19.52**	**41.42**
CD (p= 0.05)	TS	2.18*	3.10*	4.24*
	CS	2.67*	3.79*	5.20*
	TS X CS	NS	NS	NS

CT- Conventional tillage, NT- No-tillage, TS- Tillage system, CS- Cropping system, NS- Not significance result, *- Significance result.

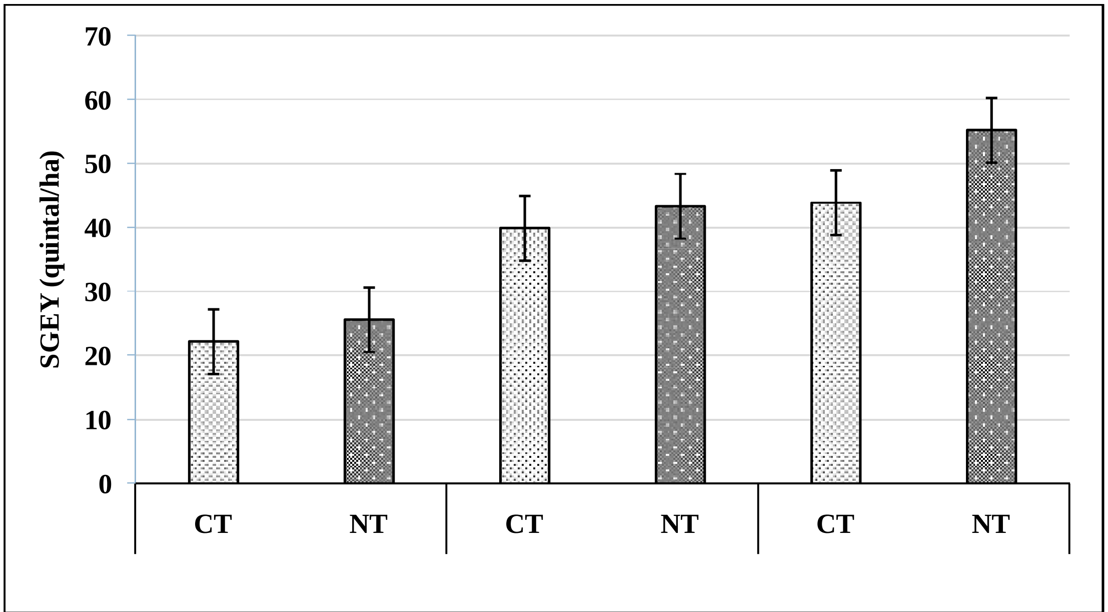

Fig. 5. Long-term impact of conventional and no-tillage practises on Soybean grain equivalent yield (quintal ha^{-1}) of both (*Kharif* + *Rabi*) session.(Error bars represent standard error)

4. Conclusion

The above results of the study clearly indicate that the organic carbon, available nitrogen, phosphorus and potassium content of soil have significantly increased during 13 years of span time due to conservation agriculture (no-tillage practice), which might be due to the accumulation of a higher amount of organic matter in surface soils resulted from recycling over the years by subsequent crop residue accumulation under no-tillage. Higher productivity of different crops under NT was owing to improvements in nutrient availability, organic carbon and other soil health parameters [29].Therefore CA-based no-tillage practices are superior and sustainable for long-term crop production and maintains soil health.

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 manuscripts.

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