



REVIEW ARTICLE

Modern concept of tillage and its importance in relation to yield of crop

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Received: 08 July 2025; Accepted: 31 March 2026; Available online: Version 1.0: 31 July 2026

Cite this article: Shrikant C, Shivanshu L, Saumya S, Anmolpreet K, Mayur D. Modern concept of tillage and its importance in relation to yield of crop. Plant Science Today. 2026;13(sp5): 01-08. <https://doi.org/10.14719/pst.10528>

Abstract

Tillage is a fundamental component of crop production, influencing soil physical, chemical and biological properties that shape crop establishment, growth and yield. However, conventional intensive tillage has raised concerns due to soil degradation, resource use inefficiency and rising production costs. This review synthesises current concepts and practices in modern tillage, including minimum tillage, zero tillage, conservation tillage, ridge tillage and puddling, with emphasis on their agronomic, environmental and economic implications. The review highlights how reduced- and zero-tillage systems improve soil organic matter, enhance moisture retention, lower erosion and reduce greenhouse gas emissions, while also noting challenges such as weed pressure, equipment requirements and early-season germination issues. Evidence from recent studies indicates that modern tillage practices can maintain or improve yields when integrated with residue management and appropriate crop rotations. The paper also identifies knowledge gaps related to long-term soil health impacts and site-specific tillage recommendations. Overall, modern tillage approaches offer promising pathways for sustainable crop production, but their successful adoption requires careful planning, farmer training and adaptation to local soil and climate conditions.

Keywords: crop; minimum; production; tillage; yield; zero tillage

Introduction

Tillage is a fundamental agronomic practice that modifies soil physical, chemical and biological properties to create favourable conditions for crop establishment and growth (1). By influencing soil structure, aeration, moisture availability and seedbed conditions, tillage plays a critical role in determining early crop performance and final yield. Despite its long history and widespread adoption, tillage remains one of the most energy-intensive and influential operations in crop production systems.

Conventional tillage practices, characterised by repeated and intensive soil disturbance, have raised serious concerns regarding long-term soil sustainability. Excessive tillage has been associated with soil structural degradation, increased bulk density and compaction, accelerated erosion, loss of soil organic matter, higher fuel and labour costs and increased greenhouse gas emissions (2-4). These negative impacts not only reduce soil productivity but also threaten the environmental sustainability of modern agricultural systems, particularly under conditions of climate variability and resource scarcity.

In response to these challenges, modern tillage systems such as minimum tillage, zero tillage, conservation tillage, ridge tillage and puddling have been developed and increasingly adopted worldwide (5). Tillage operations may be classified as on-season or off-season depending on their timing relative to crop establishment (6, 7) and as primary or secondary tillage based on depth and

intensity. Primary tillage generally involves deep plowing to loosen soil and break compact layers, whereas secondary tillage refines the seedbed for planting (8).

Despite its benefits, intensive and repeated tillage has been associated with adverse effects on soil quality, including compaction, loss of soil organic matter, increased erosion and disruption of soil biological processes (9). Improper tillage intensity can negatively affect soil temperature, water availability and gaseous exchange, leading to delayed emergence, restricted root growth and yield instability, particularly under dry or marginal conditions (10-12). Tillage-induced changes in bulk density and soil strength strongly influence aeration and water retention, thereby affecting plant growth and productivity (13). Moreover, excessive soil disturbance accelerates structural degradation and increases vulnerability to erosion (14).

Growing concerns over soil degradation, rising fuel costs and climate change have driven the development of modern tillage systems aimed at reducing soil disturbance while maintaining crop productivity. This review hypothesises that modern tillage systems provide agronomic and environmental benefits only when they are economically sustainable and adapted to local soil-climate conditions. Accordingly, the objectives of this review are to (i) outline the purposes and classifications of tillage, (ii) describe modern tillage concepts and (iii) critically assess their effects on crop yield in relation to soil health and economic performance.

Tillage purpose

Tillage is performed to modify soil conditions in ways that support crop establishment, growth and productivity. Its purposes can be broadly classified into improving soil physical properties, managing weeds and pests, regulating soil moisture and preparing an optimal seedbed (Fig. 1). Key tillage operations used in agricultural systems include: subsoiling, clean tillage, blind tillage, dry tillage and wet tillage.

Subsoiling

Subsoiling is carried out to break hard pans or compacted soil layers formed through repeated tillage at the same depth or heavy machinery use. Chiseling is also used to lessen soil compaction. When heavy machinery is utilised for field operations, sowing, harvesting and transportation, or in a rice-wheat cropping system, subsoiling or chiseling is necessary once every 3 to 4 years (15). Nonetheless, subsoiling is carried out to increased soil volume for crop cultivation; percolation of surplus water; reduction of surface runoff and soil erosion; and penetration of crop plant roots into the deeper soil layer for nutrient and moisture extraction (16).

Clean tillage

Clean tillage refers to the practice in which the entire field surface is repeatedly cultivated to uproot and eliminate all existing vegetation, leaving the soil free of weeds throughout the cropping season. This system is primarily adopted to achieve effective weed control and to reduce the carryover of soil-borne pests and diseases that may survive on crop residues or volunteer plants (17). By maintaining a weed-free seedbed, clean tillage minimises competition for nutrients, moisture and light during the critical early stages of crop establishment. However, prolonged use of clean tillage may increase soil disturbance, accelerate organic matter decomposition and enhance the risk of erosion, particularly under sloping or light-textured soils.

Blind tillage (Hoeing)

Blind tillage, commonly practiced through hoeing, is carried out either before crop emergence or during the early growth stages of the crop without causing injury to the planted seeds or young seedlings. This practice is widely used in crops such as sugarcane, potato and other row crops to control emerging weeds at a shallow depth (18). Blind tillage disrupts weed seedlings at their most vulnerable stage, thereby reducing weed pressure before crop canopy development. In addition to weed control, hoeing improves soil aeration and breaks surface crusts, facilitating better root development and moisture infiltration. When properly timed, blind tillage serves as an effective, low-cost mechanical weed management practice, especially in systems aiming to reduce dependence on chemical herbicides.

Dry

For crops that are seeded or planted in dryland conditions with enough moisture for seed germination, dry tillage is used. Broadcast rice, jute, wheat, oilseed crops, legumes, potatoes and vegetable crops can all benefit from this. When the soil is sufficiently wet (21–23 %), dry tillage is carried out (19). It improves soil aeration, increases permeability and enhances water retention by breaking surface crusts, thereby creating a favourable environment for root growth and microbial activity (20).

Wet tillage (Puddling)

Wet tillage or puddling is used mainly in lowland rice systems. Repeated plowing under standing water disperses soil particles and forms a soft, muddy layer. To prevent water loss from percolation and to produce a soft seedbed for rice planting, puddling forms an impermeable layer under the subsoil (21). The soil structure and the soil particles that are separated during puddling are destroyed by wet tillage. After wet tillage, planking helps to compact and level the soil. Puddling speeds up the transplanting process and seedling establishment. Wet tillage is often done with wetland plows or old dryland plows (22).

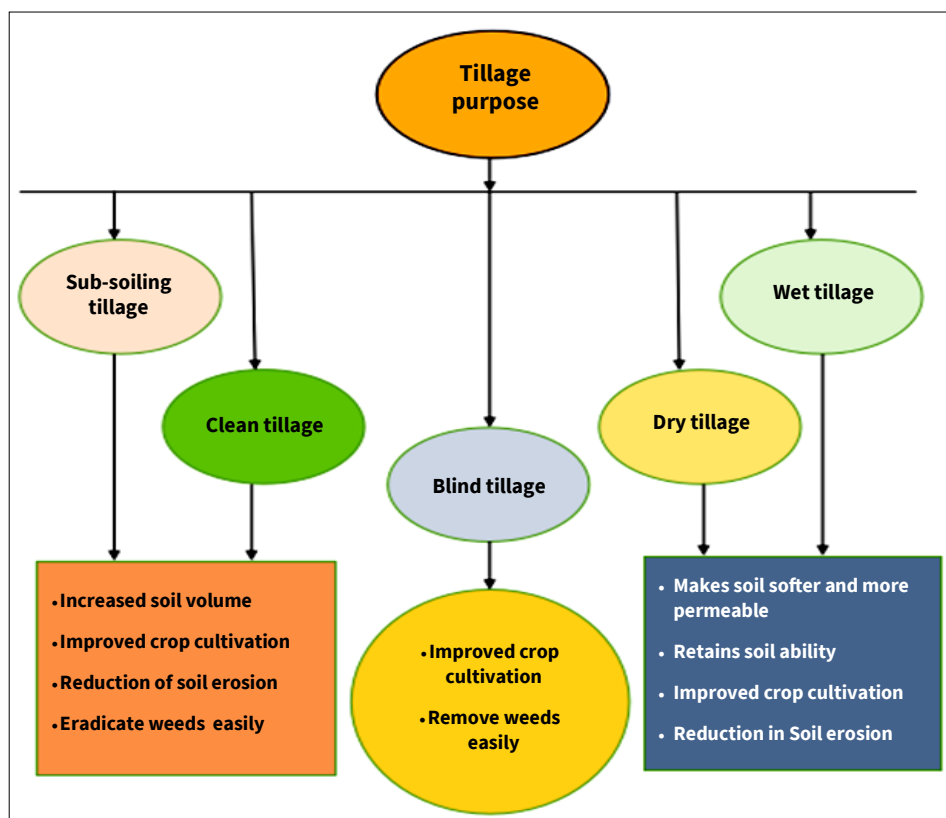


Fig. 1. Major purposes of tillage and their associated characteristics.

Modern concepts in tillage

Modern tillage systems refer to soil management practices developed to reduce the intensity and frequency of soil disturbance while maintaining or enhancing crop productivity. These systems evolved in response to the limitations of conventional tillage, which relies on repeated primary and secondary operations that disturb soil structure, increase energy and labour costs and accelerate soil degradation (23). Continuous use of heavy tillage implements often leads to subsurface compaction, reduced water infiltration, increased runoff and erosion and rapid depletion of soil organic matter. Growing concerns over soil health degradation, rising fuel costs and environmental sustainability have therefore driven the adoption of modern tillage approaches that aim to conserve soil resources, improve water-use efficiency and ensure long-term agricultural sustainability (24, 25).

Modern tillage concepts encompass a range of practices designed to minimise soil disturbance, retain crop residues and optimise input use. The major modern tillage systems are described below based on their defining characteristics, principles, advantages, limitations and suitability under different agro-ecological conditions (Table 1).

Minimum tillage

Minimum tillage reduces the number and intensity of soil operations needed to prepare a seedbed. Instead of complete soil inversion, only the upper portion of the soil is disturbed. Due to growing concerns about agricultural sustainability and the environment,

modern farming techniques have more noticeable social, ecological, economic and environmental effects (26). Plowing is by far the most time-consuming procedure when it comes to seedbed preparation. Plough-free minimum tillage techniques are significantly faster since they only disrupt or completely till a tiny portion of the 2 million pounds of soil. One practical strategy for reducing planting costs is little tillage (27). Depending on the particular minimal tillage technique used, the operational expenses differ from farm to farm and location to region. The overall acreage under cultivation and the frequency with which a farmer usually works the crop using conventional methods are two factors that affect these expenditures (28). For example, because their depreciation costs are spread across a greater land area, a large-scale farm operator usually pays less per acre for each tillage operation. At least one pass over the field is required for each minimal tillage approach and in certain situations, several passes are not required at all. For farmers, this time-saving feature might be quite important (29). Furthermore, by enabling faster cultivation, some minimal tillage techniques can improve efficiency even more than the time saved during planting and soil preparation. According to research from Indiana, Ohio and Wisconsin, minimal tillage techniques can improve water penetration, especially in regions with sloping terrain and deep, slowly permeable soils (30). The uneven seedbed that is usually associated with minimum tillage techniques is expected to reduce runoff on steeper slopes, particularly when the tillage operation is following contour lines (31).

Table 1. Different modern concepts of tillage with its advantages and disadvantages

Modern concept of tillage	Advantages	Disadvantages	References
1. Minimum tillage	• Reduced soil erosion • Improved soil health • Increased organic matter • Lower costs • Less soil competition • Improved soil fertility • Reduces labor, saves time • Improves soil tilth	• Reduced soil aeration • Increased weeds and pests • Seed germination is lower	26, 28, 29
2. Zero tillage (no tillage)	• Increases organic matter • Reduces soil erosion • Improves water quality • Reduces machinery wear • Improves soil conditions • Improves high infiltration	• No tillage is risky • Decreased crop yield in the long run • Seed germination is lower • Sowing operations are difficult	34, 36, 38
3. Conservation tillage	• Less soil compaction • Less soil erosion • Reduced erosion • Moisture conservation • Stabilises soil temperature • Improved soil fertility • Improved quality of surface water • Improved yields	• Low germination of seeds • Reduction of nodulation in legume crops • Difficulty in sowing	11, 37
4. Ridge tillage	• Reduces soil permeability • Control weeds • Improves water and nutrient availability	• Seed germination is lower • Less water holding capacity • Wind and water erosion • Destruction of soil pores • Destroys soil aggregates • Can cause water logging • Lowers soil strength	19, 49
5. Puddling or wet tillage			50, 52

Zero tillage (no-tillage)

Zero tillage involves sowing directly into the residues of the previous crop without any prior land preparation, with weeds controlled primarily by herbicides. Well-draining, coarse-textured soils with strong biological activity and a sufficient amount of crop waste for mulching are suitable for zero tillage (32). These circumstances are often seen in humid and sub-humid areas with soil types that are alfisols, oxidisols and ultisols. No-till agriculture is essentially the technique of planting a new crop in the remains of an old crop without cultivating the soil or preparing the seedbed beforehand. This is only feasible if herbicides are used to kill weeds before the next crop is planted (33). A coarse-textured surface horizon, effective internal drainage, a high level of biological activity in the soil fauna, a good soil structure from the start and a sufficient amount of crop residue for mulching are all considered prerequisites for zero tillage (34). Among the several methods for achieving zero tillage is the application of till-planting techniques. Before a small strip is opened into which seeds are sowed and covered by the planter, the preceding row of crops must be cleared using a broad sweep. Herbicide functions are being expanded in this instance (35). An extensive range of non-selective herbicides, including glyphosate, paraquat and diquat, are used to methodically eliminate the existing vegetation before planting can start. One advantage of zero-tilled soils is that they often have a more uniform structure and a greater earthworm concentration. As a result of the absence of mineralisation, the soil's organic matter content increases (36). Because of the mulch, surface runoff is decreased. Crop yields from no-tillage farming are frequently thought to be on par with or even higher than those from traditional tillage farming, particularly on well-drained to moderately well-drained soils. With very few exceptions, the water content of the soil is often significantly higher in no-till systems than it is in conventional tillage systems (37). Since the mulch stops water from evaporating on the soil surface, its presence on the soil surface significantly reduces the amount of water that evaporates when the crop canopy is not covering the soil surface. Until the crop canopy is fully grown and the majority of cropland has developed a canopy of crops, there is no discernible difference in the quantity of soil water evaporation from the soil between regular tillage and no-tillage practices (38).

Conservation tillage

Conservation tillage refers to systems that maintain at least 30 % crop residue cover on the soil surface after planting to minimise erosion and improve water retention. Seedbed preparation and sowing procedures are hampered by the leftovers that remain on the soil surface (39). After being taken from the soil, organic wastes are not reworked that is, they are not put back into the soil during the conservation tillage process. It stops the loss of soil moisture due to erosion or evaporation by leaving it on the surface instead of utilising it as a barrier (40). The process of raking stubble over the soil surface, also known as stubble mulch tillage, creates a layer that shields the soil from erosion. The process of planting is frequently impeded by residues that remain on the soil surface. This is because they make it impossible to finish the seed planting process and prepare the seed beds (11, 37). By using tools that undermine residues, deplete the soil and destroy weed roots and their seedlings, this method is utilised all year long to manage weeds in a range of crops. There are several benefits to this strategy, one of which is the potential to lessen the need for tillage, an energy-saving practice that ultimately results in energy savings (41). There is a need to make adjustments to the soil

to improve its physical qualities to be able to improve it beneficially. Reducing the amount of water that evaporates from fields will be feasible with the use of these techniques (42). Using these techniques causes water to evaporate, which is the cause of this. If an approach to tillage reduces soil or water losses in comparison to moldboard plowing in any of the following ways, it can be regarded as conserving tillage: if it reduces soil or water losses in comparison to moldboard plowing, etc (43). This involves using a moldboard plow to tiller the soil initially, followed by harrows to prepare the seedbed. Contouring is one of the conservation tillage techniques used for planting on ridges and slopes, as well as for planting across slopes. Conservation tillage is a very efficient way to reduce erosion in small watersheds and field plots (44). Maize residue utilisation in the Midwest has resulted in a 75 % reduction in soil loss. Even more erosive strategies, such as maize and soybean rotations, can be used to reach this goal. By using conservation tillage instead of conventional tillage, there may reduce erosion by up to 50 %. According to research, erosion may be reduced by half when 30 % of the soil is covered by plants as opposed to bare soil (45).

Ridge tillage

Ridge tillage, as the name implies, is the act of concentrating and scraping topsoil in a particular location to elevate the seedbed above the local terrain. To create a sustainable agricultural system in an ecologically responsible way, it appears that the ridge-tillage system is also a crucial part or subsystem of a successful market-oriented agriculture strategy (46). Tractor-driven ridge-tillage tools are frequently used in contemporary agriculture to complete this operation rather than traditional hand-operated tools. Ridge tillage has been used in traditional agriculture for a long time across a range of soil types, rainfall patterns and biological settings, as well as crops, socioeconomic circumstances and historical crops (47). A specialised cultivator is used to dig a trench 12–20 cm deep between rows of soybeans (*Glycine max* (L.) Merr.) or maize (*Zea mays* L.). Every year, regardless of the weather, the same crops are cultivated on the same high hills (48). Thus, it is a sort of reduced-tillage system where inter-cultivation, carried out four to six weeks after the seeding of a row crop, can help control weeds to a certain degree when the ridges are reforming or developing (19). As a result, inter-cultivation during the development of ridges is a sort of reduced-tillage system that can help manage weeds to a certain degree. In an attempt to cut expenses, efforts are underway to decrease the usage of pesticides and to do away with secondary and primary tillage. As with the traditional practice, ridge-tillage offers substantial benefits for controlling erosion and managing water in contemporary agriculture (49).

Puddling or wet tillage

Puddling, also known as wet tillage, is a type of tillage that is typically used on wet soils, which are soils that contain standing water. Typically, this kind of tillage is applied to soils that contain standing water. Plowing the ground repeatedly while standing water is present until the soil becomes muddy and mushy is known as a puddling operation (50). In addition to providing a soft seedbed for rice cultivation, an impermeable layer under a pond's surface helps minimise water loss through deep percolation. One of the numerous advantages of ponding is that it may limit water loss by deep percolation by forming an impermeable layer under the surface (51). The best method for incorporating weeds and green manures into the soil is to simultaneously puddle them in both directions. It is commonly recognised that wet tillage breaks down the structure of

the soil and the soil particles that are separated during puddling eventually settle as they are reabsorbed and reintegrated into the soil (52). It is evident that the only technique available for preparing the ground for the transplantation of semi-aquatic agricultural plants, like rice, is wet tillage. While this is true, puddling can have a variety of consequences on soil quality, depending on the soil's texture and composition (53). Sesquioxides and nonexpanding clay minerals are frequent in fine-textured soils with a well-developed soil structure and a large proportion of water-stable aggregates. Even when submerged in water, these soils maintain a significant amount of their soil aggregates when there isn't a puddle. In these soils, puddling is required to remove soil aggregates thoroughly (54). When aggregates are removed, the physical and chemical characteristics of the soils (such as pH, potential and the solubility of plant nutrients) are greatly impacted. Although clay minerals come in a variety of forms, even when fine-textured soils include a large number of clay mineral variations, they can scatter quickly without wet tiling (51).

Effects of tillage on yield

Tillage affects crop yield through its influence on soil physical condition, water availability, root growth and nutrient dynamics. The degree of soil disturbance, residue management and resulting changes in porosity and compaction determine the soil environment for crop establishment and subsequent growth (55). Variations in these factors across tillage systems lead to contrasting yield responses depending on soil type, climate, crop and management practices (56).

Soil physical changes and yield formation

Tillage systems significantly modify soil bulk density, porosity, aggregation and penetration resistance, which collectively regulate root growth and nutrient uptake. Conventional tillage generally produces a loose surface soil favourable for early crop establishment but may induce subsurface compaction due to repeated mechanical operations. In contrast, minimum and conservation tillage systems often improve soil structure, permeability and pore connectivity over time, enhancing soil productivity while reducing fuel use and erosion risks (57).

Long-term adoption of minimum tillage across crop rotations has been shown to improve soil physical, hydro-physical and biological properties, resulting in improved water infiltration, drainage and resistance to wind and water erosion. These improvements contribute to more efficient seedbed preparation and sustainable yield maintenance with reduced energy inputs.

Water availability and root development

Reduced soil disturbance and residue retention under minimum and conservation tillage enhance soil moisture conservation by increasing infiltration and reducing evaporation losses. Improved moisture availability promotes deeper and more extensive root systems, particularly under rainfed or low-rainfall conditions. These benefits are especially important in seasons with limited precipitation, where minimum tillage systems often perform equal to or slightly better than conventional tillage in terms of yield.

Effects on emergence and early crop growth

Seedling emergence and early growth responses to tillage vary with soil condition and climate. Conventional tillage frequently results in faster and more uniform emergence due to finer seedbed preparation, as observed in wheat systems (58). However, reduced

or minimum tillage systems may exhibit slightly lower or delayed germination, especially under compacted or cooler soils. Despite this, improved moisture conservation and reduced biotic stresses (such as seed damage) often compensate for early differences, resulting in comparable plant populations across tillage systems.

Crop yield responses under different tillage systems

Crop yield responses to tillage systems are crop- and environment-specific. Studies comparing conventional, minimum and no-tillage systems have reported that conventional tillage can enhance yield attributes and grain yield in certain crops such as wheat, particularly during the initial years of adoption (58). However, minimum tillage systems often produce yields comparable to conventional tillage across crops such as maize, soybean and wheat, while offering greater economic returns due to lower operational costs (57, 59).

Interactions between tillage and nutrient management further influence yield outcomes. Nitrogen application significantly increases grain yield across tillage systems, with optimised nitrogen rates under minimum tillage producing yields comparable to conventional systems (60). Additionally, specialised low-disturbance techniques such as strip tillage, wheel-track planting and plough-based minimum tillage have demonstrated advantages in moisture conservation, cost reduction and yield stability, although their effectiveness depends on soil type and equipment adaptability (61).

Overall, these findings indicate that no single tillage system is universally superior. Yield performance under different tillage practices depends on soil characteristics, crop type, climatic conditions and complementary management practices. Minimum and conservation tillage systems, when properly managed, offer sustainable alternatives to conventional tillage by maintaining yield while improving soil health and reducing production costs.

Conclusion

Modern tillage systems such as minimum tillage, zero tillage, conservation tillage, ridge tillage and puddling offer important opportunities to enhance soil health, conserve moisture, reduce erosion and improve long-term agricultural sustainability. Tillage activities are principally responsible for the distortion of soil structure caused by soil disturbance. However, the benefits of modern tillage practices are highly context-specific. Soil type, climate, residue availability, machinery access and crop requirements influence the suitability and performance of each tillage system. To mitigate these impacts, tillage reduction strategies are used. The contemporary tillage approach leaves around half of the crop residue in the soil after harvest, with just limited tillage activities carried out. Modern tillage techniques can completely transform contemporary agriculture by increasing soil health, reducing soil erosion, maintaining moisture and increasing crop yield. The approach is affordable and cost-effective and might ultimately result in significant financial savings for farmers. Effective adoption of current tillage practices requires the capacity to learn new skills and adapt to new agricultural approaches. By employing proper planning, crop management and soil conservation techniques, farmers may benefit from contemporary tillage techniques and contribute to a more sustainable agricultural future. Modern tillage techniques may have several drawbacks despite their many benefits. While the soil adjusts to the new farming approach, there could be some initial yield drops

and the process might not work for all crops. These drawbacks might be lessened, though, with proper planning, crop rotation and soil management practices. Adoption of modern tillage tactics requires a willingness to adapt and a willingness to change traditional agricultural ways. Farmers who want to use the contemporary tillage idea need to be ready to invest in new equipment and technology and undergo training. Future research should focus on long-term impacts on soil carbon, system resilience under climate variability and optimised combinations of tillage, nutrients and residue strategies for diverse agroecosystems.

Acknowledgements

The authors express their profound gratitude to Lovely Professional University, Punjab, for providing the necessary facilities and support for the conduct of the research trial and for fulfilling all requirements of the study.

Authors' contributions

SC conceptualised the review structure. SL assisted in literature collection. SS contributed significantly to manuscript writing. AK supported in organising and summarising the content. MD supervised the overall work and performed the final editing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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