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Conservation Agriculture: A Review of Plant Residue use with Zero Tillage and Crop Rotation

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ABSTRACT

Although Conservation Agriculture (CA) techniques have long been known, they are still rarely applied by farmers in their farming. Three principles of conservation agriculture: 1). zero tillage (ZT), 2). Cover crop used and 3). Crop rotations have spread throughout the world, but in practice, only one or two of the three principles used and vary greatly (The combination of zero tillage and crop residue is more efficient in utilizing rainwater and a more resilient agronomic production system compared to conventional tillage (CT) or zero tillage (ZT) without crop residue application. Not using crop residue in the system can result in decreased production and even yield zero. Zero tillage applications that are not combined with ground cover will result in poor farming performance. In reas with low rainfall, the yields were highest obtained in farms that combined zero treatments and the use of crop residues, whereas in rainfed areas with conventional (CT) systems, when residues were removed from no-till (ZT) systems, wheat and maize yields were drastically reduced. Furthermore, in many small-scale farms, the residue yield is low and has many competing uses. Crop residues are generally burned in the fields or fed to livestock. For successful farming using CA techniques, at least a combination of 2 principles of conservation agriculture is needed, namely the use of crop residues and ZT as soil cover or the use of crop residues as soil cover with crop rotation, can provide better results than only applying one of the three CA principles.

Key words: Conservation agriculture, Ground covers, Plant residue.

Utilizing natural resources rationally and sustainably needs to be done; this is a preservation effort for the environment for current and future generations. To meet the need for food along with population growth, it is necessary to develop agriculture with sustainable production. However, in reality, many challenges must be faced, which are feared to threaten the sustainability of agricultural development. Improved business and a better environment for sustainable farming practices show that the excessive use of fertilizers and pesticides has a negative impact on farm production and income, as well as damaging some environmental factors. (Kassam *et al*., 2022; Teng *et al.,* 2024; Wang *et al*., 2022).

One important aspect of sustainable development discussed is how the present generation meets its food needs while maintaining sustainable productivity for future generations; the answer is sustainable agricultural environmental management. Therefore, agricultural environmental management is aimed at achieving the goal of a healthy and sustainable environment and supporting the economy of farmer households (Hendrik *et al*., 2021; Dev *et al*., 2023; Hendrik *et al.,* 2019).

In managing the agricultural environment, it can be done in 3 ways, namely conventional techniques, modern techniques and conservation agriculture techniques. Of these three techniques, conservation agriculture is the one that can support the sustainability of agricultural production, but in practice, there are still few farmers who adopt only this technique in their farming efforts. According to (Uddin and Dhar, 2016), only a small number of farmers in the world follow this practice (8-10%), even though conservation agriculture has many benefits, including maintaining the sustainability of the natural environment (Angon and Roy, 2023; Rana, 2023). Whereas this technique has been proven to increase crop production yields as reported by (Staniak and Kork, 2025; Mekonnen and Gadisa, 2023), who stated that even when only one or two principles are used, in rainfed areas with dry climates, the yield at CA is 7.3% higher than that in the industrials system, possibly due to water infiltration and soil moisture greater increased.

Conventional agriculture and conservation agriculture differ mainly in three interconnected practices: Soil disturbance, soil cover and crop rotations. These differences lead to distinct effects on soil health, input use and long-term sustainability (Fig 1). Meanwhile, an experiment conducted to observe the differences in soil quality between conservation farming and conventional

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practices with wheat-corn rotation, found a large difference in yield of up to 4.7 tons/ha, while conservation farming implementing no-till (ZT) without residue retention, the yield obtained was lower compared to conventional tillagse (Kassam *et al.,* 2022; FAO, 2023). Therefore, an optimal management of crop systems is needed in the face of climate change to provide more resilient options that anticipate decreasing average rainfall and more frequent extreme drought periods. Besides that, there are variations of crop management systems such as : (1) conventional tillage vs. no-till and (2) residue management (full, partial retention, or no residue) and zero tillage. Management that combines residue retention and ZT during the dry period of the growing season provides higher soil water content and buffering than management practices involving CT and ZT without crop residue. On average, practices like zero tillage (ZT) without crop residue or conventional techniques (CT) have yields of approx 1.5 t/ha. (Wang *et al*., 2022; Dev *et al*., 2023; Oliveira *et al*., 2024). This is a much lower yield compared to the yield from a farming system that combines zero tillage with crop residues as ground cover simultaneously (Perezgrovas *et al.,* 2014; Derpsch *et al.,* 2024).

The concept of conservation agriculture

Enhancement of natural biological processes above and below ground can be achieved by applying the three principles of agricultural conservation. This is done by reducing mechanical tillage to a minimum and organic nutrients are used in amounts that do not interfere with biological processes. Or applied at optimal levels.

In addition, Conservation Agriculture (CA) is a concept of efficient and sustainable crop production to gain profits while maintaining environmental sustainability. CA are characterized by three principles that are interrelated and applied simultaneously (Table 1): No-till systems, the right depth of seed planting, soil cover with crop residues or previous plant residues left on the ground and crop rotations. During the congress of the organization of food and agriculture (FAO) and European Federation of Conservation Agriculture in Madrid in 2001, the term CA was adopted. Systems CA are also referred to as resilient systems, with crop seeds, direct planting, permanent soil cover and crop rotation when no-till is carried out. The terms of CA can be explained as follows:

(1). Soil minimal disturbances: the disturbed area should not exceed 15 cm or 25% the area cut. Periodic tillage did not disturb areas larger than the limits stated.

(2). Ground cover consists of three categories, first category: 30.0-60.0%, second category: 61-90% and third category: >91%. Ground cover is measured as less than 30% after planting and will not be considered CA. (3). Crop rotations: Must at least involve three different crops, even if there are no pest attacks (Araya *et al.,* 2024; Rodenburg *et al*., 2020). Interaction and benefits of three priciples of Conservation Agriculture :

Some of the important characteristics of CA: 1). On the surface of the soil and the roots that remain below the soil surface, where active biota and carbon, organic matter such as leaf or stem remains are added; 2). There is recycling of plant nutrients, carbon and water; 3) The infiltration rate is greater than the rainfall rate and the soil porosity is maintained by the organic soil cover; 4). The combination of living and dead fractions provided by organic matter, which together form soil, is an important part of the dynamics, flexible and sustainable, as well as providing plant nutrients and absorbing water; 5). Metabolic functions operate on non-organic living matter for maintaining potential ionic compounds, which are supplied by the plant's nutrients into its body cells. Organic matter after death acts as a slow-release mechanism in a symbiotic arrangement that makes nutrients available to plants 6). Various complex molecules break down organic matter and are converted into various labile and resistant substances according to the substrate composition, through biotic processes by other soil leaving organisms, materials with different levels of severe damage resistance 7). Over time, some of the less durable residues will release durable carbon and nutrients. Organic acids are produced that help

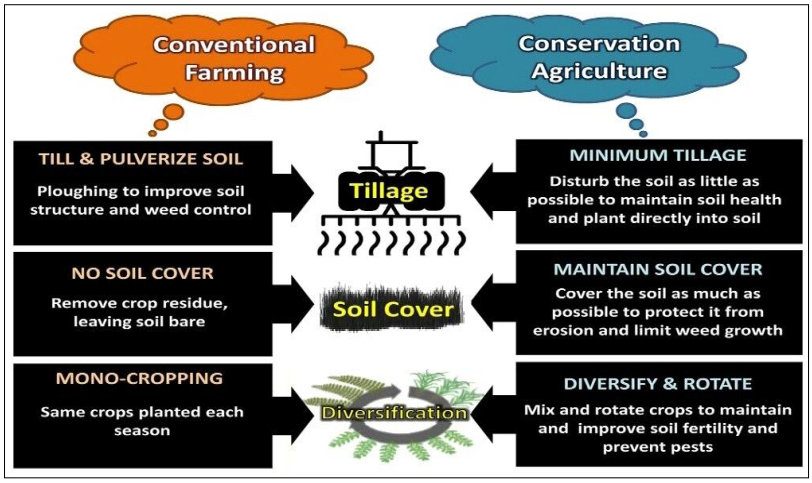


Fig 1: Difference between conventional and conservation agriculture.

transport lime into the soil profile and mobilize nutrients such as phosphate. In addition, less durable residues also break down mineral particles as part of the soil weathering process 8). As a transformation product that makes a significant contribution to the Cation Capacity Exchange, providing organic molecules or soil CEC, increasing soil buffering capacity against PH changes, 9). Microorganisms such as earthworms are increasing burrowing activities (Kassam *et al.,* 2022; Angon and Roy, 2023; Oliveira *et al*., 2024; Araya *et al.,* 2024; Rodenburg *et al*., 2020).

Continuous and repeatable crop and water production can be ensured by CA techniques. This is done by supporting soil improvements as an environmental root (Aleminew, 2024; Biswakarma *et al*., 2021). CA ranges according to one or more of the three main principles; CA is not a single technology. However, in the field, CA works best when all three main features are adequately combined, which differs significantly from conventional farming (Oliveira *et al*., 2024; Sumberg and Giller, 2021; Mulimbi *et al*., 2023). On land that has been first cleared for agriculture, CA can maintain and replicate the desirable characteristics of the native soil. Whereas on degraded land that has been converted to a better physical condition, after organic mulch remains on the soil surface at all times CA should avoid tillage, as for surface organisms and the underlying substrate this provides protection; especially in using different crop and cover crop sequences multi-year rotations; and to provides N proportion significantly depending on plant nitrogen. CA can maintain the land health that has been previously opened, but is still in good condition and can regenerate it when the land condition is poor (Dev *et al*., 2023). CA also relies on other plant nutrients released through the biological transformation. In cases of deficiencies of specific nutrients, this can be obtained from the supply of appropriate fertilizers and organic matter supplies micronutrients (Oliveira *et al*., 2024; Biswakarma *et al*., 2021).

Plant residues as ground cover and zero tillage

The damage to organic matter on soil surfaces is currently seen as a result of maximum soil tillage and mixing. Severe soil erosion and hardening leading to decreased soil fertility are the result of excessive tillage. However, tillage in agriculture has long been carried out as the main process that is believed to increase soil fertility through mineralization that occurs in the soil. To eliminate this mistaken belief, the No-Tillage (NT) system approach was introduced, which is the main farming system approach that meets the requirements of a sustainable agricultural production system (Sumberg and Giller, 2021; Mulimbi *et al*., 2023).

Although zero tillage is a key factor in CA, in its application, it needs to be supported by the use of crop residues that can restore soil fertility and reduce erosion rates, as well as increase productivity. This has been proven by research (Biswakarma *et al*., 2021; Dev *et al*., 2023; Tankosić *et al*., 2023), that conservation agriculture that applies zero tillage without application of crop residues as soil cover gives lower yields compared to conventional farming practices. In the application of crop residues as soil cover, plant nutrients are provided by soil organic matter, which is combined with water absorption to form the dynamics of soil formation, resilience and sustainability (Biswakarma *et al*., 2021; Swaminathan *et al*., 2021). While ZT only indicates no-till, in reality, it is necessary to implement several components in a conservation farming system to ensure higher and better yields compared to conventional tillage (CT) systems. Organic matter conserving process in the soil by combining no-till farming and using crop residues as ground cover can allow the soil to remain productive for longer (Scavo *et al.,* 2022). In addition, the time and labor to produce crops can increase. Conservation agriculture's principle of minimizing mechanical disturbance to the soil and crop residues as ground cover could be understood as a sustainable agricultural technology to meet future demand. No-till (NT) tillage not combined with soil cover will result in poor production. Crop residue retention is an important component to increase and maintain C in soil. Yield factors that increase yield will be followed by an increase in the amount of residue available for potential soil C storage. In both NT and CT systems, fertility management can be the most important factor to increase residue production and soil C storage, as well as crop rotation, which is very important to increase C input and soil C in low-input productivity systems (Game, 2021; Malo, 2021; Phogat *et al*., 2020). However, some important things to consider are,

Table 1: The three main principles of conservation agriculture (CA) and their interactions.

Principle	Description	Benefits and interactions
Minimum soil disturbance	Little to no mechanical soil disturbance, primarily no-till or reduced tillage.	Preserves soil structure, organic matter and soil organisms; improves water infiltration and reduces erosion. Supports soil health for nutrient cycling.
Permanent soil cover	Maintaining a continuous cover on the soil surface using crop residues, cover crops, or mulches.	Protects soil from erosion, reduces evaporation, conserves moisture, provides habitat for soil biodiversity and enhances carbon sequestration.
Diversification of plant species	Crop rotation, intercropping and diversification of crops planted in sequence or simultaneously	Improves soil fertility, breaks pest and disease cycles, increases biodiversity, enhances resilience and reduces crop failure risk.

how long it takes to till the land after the native vegetation has been converted to agricultural production; what are previous crops and information on the amount of residue distribution, soils type, textures, organics carbon content, pHs, cropping quality history and amount of ground cover (grass vs legumes), soil moistures content at seedings/ planting time, soil temperatures and densities, seeding equipments type uses and uniforms spacing, depth achieved in all treatments and number of plants required, at the time of sowing, what percentage of soil surfaces is disturbing ?, what percentages of soil surfaces is covering by residues after seeding per year in each system?., what type and amount of biomass are produced and returned to the soil?. Furthermore, no-till systems cannot be used if the soil surface is disturbed > 50%, but mulching or other forms of tillage can be used (Game, 2021; Behera *et al*., 2023; Chahal *et al*., 2025).

Plant residues as ground cover and crop rotation

The third principle of conservation agriculture is crop rotation, which involves more than two plant species. According to an article entitled "The roles of conservation agriculture and sustainable agriculture" published by the philosophical transactions of the royal society journals, crop rotation can be used as a control to prevent plant diseases. In the process of certain crop rotations, pests such as insects and weeds will not be allowed to enter and form patterns. In addition, most leaf plant diseases are also specific to certain plant species and some types of plants will act as natural insecticides and herbicides. Therefore, rotation can help reduce the risk of economic losses due to plant diseases and eliminate problems with declining crop yields (Chahal *et al*., 2021). Crop rotation can also help to build healthy soil with good structure. Rotational planting allows for the formation of a wide root zone where deep-rooted plants can break up compacted layers, allowing for better water infiltration. While shallow-rooted plants maintain the structure of the topsoil (Valujeva *et al.*, 2022).

Ponisio and Ehrlich state that under rainfed conditions in a dry climate, even when only one or two principles are used, yields in conservation agriculture are higher 07.30% than in industrial systems, possibly due to increased water infiltration and soil moisture (Bhatt *et al*., 2023). The study of (Bhatt *et al*., 2023) explored whether an agriculture conservation wheat-based (CAW) productions system can cope better to climate extremes than conventional tillage systems (CTW) has made four main conclusions: i) during bad years, losses wheat yields were lower in CAW than in CTW, This means that wheat-based conservation farming practices are an efficient technique to cope with unpredictable climate changes. ii) there is merit in promoting CAW, as it provides yield benefits in extreme climates. In addition, increasing farmers' knowledge and confidence through regular training in CAW is also very important. iii) Besides agricultural size, CAW also functions in measuring climate risk adaptation. iv) To adapt to rainfall variability, where crop rotation diversity is inadequate, CAW can be an effective way. Conservation agriculture (CA) systems may have distinct opportunities to grow cover crops that can enhance plant growth by adding soil organic matter, whereas conventional systems (CT) are limited by reduced moisture when the soil is tilled (Maurya *et al*., 2020), while CAW can serve as a measure of adaptation to climate risk (Bhatt *et al*., 2023; Maurya *et al*., 2020).

Important variables impacting the soil C and N storage are the crop species type and amount of C and N inputs under different crop rotations (Malo, 2021; Ponisio and Ehrlich, 2016). Crop rotation has less effect on soil C content than conservation tillage. Biomass production and C inputs increased in a system from multiple crops through pest cycles and changes in crop rotation can affect soil C and root pattern diversification (Malo, 2021).

In general, crop rotation effects on C soil content are only related to the production of soil biomass (residues and roots) and the amount retained on the ground above and below systems. High-residue harvesting crops obtain more C inputs than low-residue crops. Crop systems intensification, such as increasing crop number, increasing the number of years and also adding cover crops, can lead to increased C storage in soil. Unfortunately, there are not many studies that report on input residues, especially root biomass, which has a better rotation effect in conservation farming systems (Dev *et al.,* 2023; Malo, 2021; Aryal *et al*., 2020), whereas soil C storage was higher in zero tillage (ZT) than in conventional tillage (CT), because of the inclusion of cover crops in the rotation and not due to higher residues production. ZT soil compared to CT showed slower residue decomposition and lower N, resulting in a greater number of root shoots.

Furthermore Dev *et al*. (2023); Biswakarma *et al*. (2022); Shah *et al*. (2021), stated that the success of conservation farming systems depended on diversifications of crop rotation and permanent cover crops applications without soil preparation (Cooper *et al*., 2017; Kassam *et al*., 2019; Chahal *et al*., 2021; Yang *et al.,* 2024). Finally, although various studies show that conservation agriculture can be a path to sustainable agricultural productivity, further research is still needed to find the appropriate combination of the 3 principles of conservation agriculture for different climate conditions.

Farmers in East Nusa Tenggara are mostly small farmers with narrow land areas. The crop types cultivated are horticultural crops and food crops such as dryland rice and corn. Corn is generally planted in the rainy season once a year. The purpose is to meet the household's needs or subsistence farmers and the rainy season is 4-5 months, with low and uncertain yields as well as greater crop failure. Rice farmers use more conventional or modern techniques than conservation farming, relying on agricultural tools such as tractors. And also still rely on fertilizers and pesticides that can lead to environmental problems, no tillage principles of agriculture conservation carried out by farmers are influenced more by conventional techniques that have been passed down

from generation to generation. Meanwhile, crop residues that should be used as ground cover compete with other uses such as animal feed (Hendrik *et al*., 2021; Dev *et al*., 2023; Tankosić *et al*., 2023; Waha *et al*., 2018; Gugalia, 2021) and the remaining crop retention in the fields will be burned when planting begins. Farmers do not do much crop rotation because of climate change constraints and limited water resources. This situation is exacerbated by economic constraints and low levels of education among farmers (Hendrik *et al*., 2021). Training on conservation agriculture practices helps farmers understand the importance of conservation agriculture for maintaining long-term dryland productivity. Institutional support can be provided by continuously improving incentives and services related to conservation agriculture that farmers need.

CONCLUSION

Conservation Agriculture offers long-term sustainability benefits for soil, water, biodiversity and climate, but faces challenges like initial costs, farmer education and management of weeds and residues. The combination of the 2nd principle of Conservation Agriculture (CA) crop residue retention with the 1st principle of no tillage or with the 3rd principle of crop rotation provides many advantages for agricultural sustainability compared to conventional agriculture. This can affect ecosystem services. Therefore, agricultural inputs and training support for farmers related to agricultural conservation principles are also needed. Compared to conventional agriculture, Conservation Agriculture (CA) can change the process and nature of the soil. Educational institutions and government support can be provided by providing policies, incentives and services needed by farmers related to conservation agriculture and discouraging harmful practices, such as the excessive use of pesticides.

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Disclaimers

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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