REVIEW ARTICLE

ROLE OF CONSERVATIONAL AGRICULTURE IN SUSTAINABLE FARMING

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Received-02.09.2020, Revised-23.09.2020

Abstract: Conservation tillage has been considered an established technology for growing farm income, but its implementation is still uncertain in the semi-arid part of western India. The most pronounced impact of conservation tillage is on the cost-saving compartment, but since conservation tillage / zero tillage / no- tillage (CT / ZT / NT) wheat farmers were able to sow the crop much earlier than their conventional counterparts, yield increases by 8%. Crop-rotations and household considerations were influencing ZT adoption. Although there are a range of constraints for continuous adoption of ZT, such as excess moisture, undulated plots, limited landholding and residue management difficulties for *kharif* crops (pearl millet, cotton). The ZT technology was also found to be efficient in reducing the farmer dependency on external inputs and ensures sustainable production of wheat.

Keywords: Crop-rotations, Physico-chemical properties, Microbiological properties, Zero-tillage

INTRODUCTION

No-tillage is characterized as planting crops in previously unprepared soil only by opening a narrow hole, trench, or band of sufficient width and depth to obtain adequate seed cover and no other preparation of soil is carried out (Phillips and Young, 1973No-tillage is the term used in North America while direct-drilling or zero tillage is used in the UK and Europe and Aerial seeding is of course the ultimate form of zero tillage. Probably about 95 percent of the practical use of no-tillage by farmers world-wide takes place in the America. A greater effort must therefore be made to transfer this truly sustainable production system primarily to Africa and Asia's tropics and warmer regions. The explanation for this, is that "no technique yet devised by mankind has been anywhere near as effective at halting soil erosion and making food production truly sustainable as no-tillage" (Baker *et al.*, 1996). The ploughing system is considered to be an inefficient use of time and fuel and causes the machines much "wear and tear". Power requirements for soil tillage are substantial and this may be a technical challenge or an economic problem in modern agriculture, but formerly this meant hard, long-lasting labour for a large percentage of all people who have ever lived on earth. Forces required are so immense that animals were used very early to make the physical stress tolerable but for every hectare in which he prepares the soil, a small farmer ploughing his field with animal traction has to walk 30 to 40 km behind his plough. Consequently, the reduction of tillage to the minimum necessary to produce a crop, has probably been in the minds of many farmers for a long time. But when the tractor showed up , where effort is reduced because the operator is sitting, the tendency went the other way and farmers began to believe that the more tillage you do, the more yield you get. More tillage leads to more erosion and degradation of soils, especially in warmer areas.

As a province, Haryana appeared on India's political map on 1 November 1966 and that area has played a vital role in the country's economic growth and agricultural development. Haryana is geographically surrounded by the North Shiwalik Hills, the South Aravali Hills, the East Yamuna River, and the West Thar Desert. It has 44.2 lakh hectares of land, comprising 1.34 per cent of the country's total geographic area. The State climate ranges from warm, semi-arid and humid with an average annual rainfall of 617 mm. In this part of the country, in fact, agriculture was older than the Harappan civilization. People in this region experienced terrible distress due to recurrent famines and droughts but continued efforts to resolve the problems and approximately 58 percent of the country is under a highly exhaustive system of rice-wheat cropping (Table 1).

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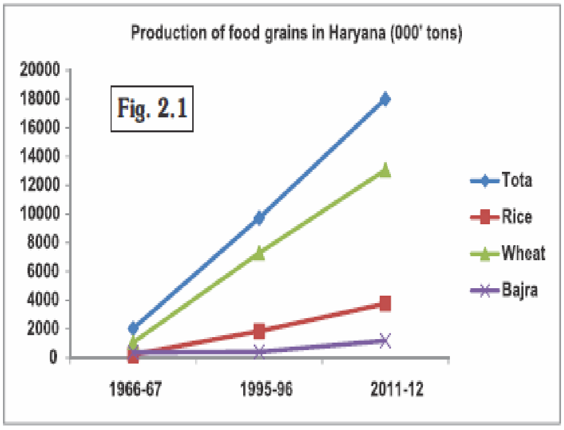
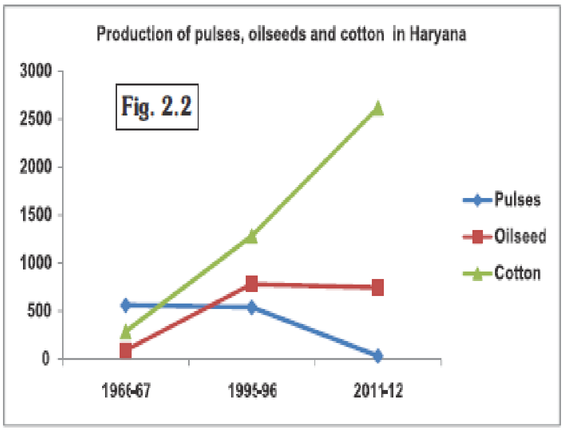
Table 1. Agricultural Zones of the State

Zone	Districts	Area %	Agricultural options
I	Panchkula, Ambala, Kurukshetra, Yamunanagar, Karnal, Kaithal, Panipat and Sonepat	32	Wheat, rice, sugarcane, maize, cows, buffaloes, and poultry
II	Sirsa, Fatehabad, Hisar, Jind, Rohtak, Faridabad and Palwal	39	Wheat, cotton, rice, sugarcane, bajra, buffaloes, cows and poultry
III	Bhiwani, Mahendergarh, Rewari, Jhajjar, Gurgaon and Mewat	29	Pearl millet, rapeseed & mustard. Mewat area is also suitable for agro-forestry, sheep and goat rearing

Fig1.1: Map showing ecology and cropping pattern zones

Note: Zone I and II have better irrigation facilities and overall infrastructure





Source: Based on data - agriharyana.nic.in/Stat_Info/Nine%20Patti.doc

Agriculture's need to consider its impact on the environment

There seems to be no alternative but to increased agricultural productivity (*i.e.* crop yield per unit area) and the associated total and individual factor productivities (*i.e.* biological output per unit of total production input and output per unit of individual factors of production such as energy, nutrients, water, labour, land and capital, to meet the global food, feed, fiber and bioenergy demand and to alleviate hunger and poverty. The resilience of production systems to biotic and abiotic stresses, especially those resulting from climate change, must also be enhanced. Therefore, the deterioration of agricultural land and ecosystem services, and the restoration of deteriorated agricultural land due to past violence, is important. Nevertheless, agricultural intensification based on intensive tillage-based production systems has generally had a negative impact on the quality of many of the important natural resources, such as soil, water, biodiversity and the related ecosystem services provided by nature (Dumanski *et al.*, 2014).

Another problem for agriculture is its environmental footprint and climate change, and agriculture accounts for about 30 per cent of overall greenhouse gas emissions of CO_2, N_2O and CH_4 while being directly affected by the impact of a changing climate (IPPC, 2014). Sustainable intensification of crop production must not only minimize the impact of climate change on crop production, but also offset the factors that cause climate change by reducing emissions and helping to sequestrate carbon in soils. Intensification should also enhance biodiversity in above and below ground crop production systems to boost ecosystem services for better productivity and a healthier environment. All these targets are achieved by a collection of soil-crop-nutrient-water-landscape system management activities known as conservation agriculture (Jat *et al.*, 2014; Farooq and Siddique, 2014). CA saves energy and mineral nitrogen use in agriculture and thus decreases greenhouse gas emissions; it increases soil biological activity, resulting in increased long-term yield and factor productivity. Although not tilling the soil is an essential but inadequate condition for truly sustainable and efficient agriculture, CA, which also includes diversification of the soil crop system, must be complemented with other techniques such as integrated pest management, plant nutrient management, weed management and water management.

Conservation agriculture definition and description

Conservation Agriculture is an approach to managing agro-ecosystems for enhanced and sustainable production, increased profits and food security, while maintaining and improving the resource base and the environment, according to the FAO (FAO, 2014a). Three related concepts characterize CA, *viz.* continuous no or minimal mechanical soil disturbance (*i.e.* no-tillage and sowing or transfer of crop seeds and direct placement of planting material in the soil; minimum soil disturbance due to cultivation, harvesting or farming, in particular small strip or band seeding disturbing less than 25% of the soil surface (FAO, 2014b); maintenance of a permanent organic soil mulch cover, in particular through crop residues, crops and cover crops; and diversification of crop species grown in series or associations by rotations and in the case of perennial crops, plant associations including a balanced mix of legume and non-legume crops. CA principles are universally applicable with locally formulated and adapted methods for all agricultural ecosystems and land usages and enhances biodiversity and natural biological processes above and below the ground surface. Soil activities such as mechanical tillage are reduced to an absolute minimum or eliminated and external inputs such as agrochemicals and mineral or organic plant nutrients are optimally implemented in ways and quantities that do not compete with or interfere with biological processes (FAO, 2014a).

CA is complemented by other known good practices, such as the use of quality seeds and the integrated management of pests, nutrients, weeds and water, and is a foundation for sustainable intensification of agricultural production (Jat *et al.*, 2014 and Farooq and Siddique, 2014). In the long term, the use of chemical fertilizers and pesticides, including herbicides, is decreased due to increased system diversity and the enhancement of biological processes in the soil and above the surface as well as to reduced erosion and leaching. The replenishment of groundwater supplies by better water absorption and decreased surface runoff and improvement of water quality due to reduced rates of pollution from agrochemicals and soil erosion. It also helps sequester carbon in soil at a rate of approximately 0.2 to 1.0 t ha^{-1} $year^{-1}$ or more depending on the location and management practices (Sá *et al.*, 2013 and Corsi *et al.*, 2014). In general, labor requirements are reduced by about 50%, which helps farmers to save on time, fuel and machinery costs (Lindwall and Sonntag, 2010) and fuel savings of around 60% or more are commonly recorded (Friedrich *et al.*, 2009).

Conservation agriculture history, evolution, and significance

In the 1940s, seeding machinery developments allowed to seed directly without any soil tillage. At the same time, Edward Faulkner in his novel "Ploughman's Folly" (Faulkner, 1945) and Masanobu Fukuoka with the "One Straw Revolution" (Fukuoka, 1975) developed theoretical concepts matching the CA principles of today but it was not until the 1960s for zero-tillage to enter into farming practice in the USA (Kassam *et al.*, 2014a). No-tillage entered Brazil in the early 1970s, where farmers, together with scientists, turned the technique into the device that is today called CA, yet it took another 20 years before CA reached substantial levels of adoption. During this time, farm equipment and agronomic practices in no-tillage systems were improved and built to maximize crop, machinery and field operations efficiency, and researchers are still producing improvements to system, soil and farmer benefits. From the early 1990s, CA began exponentially growing, leading to a revolution in southern Brazil, Argentina and Paraguay's agriculture. In 2008/09 the total cropland area under CA was estimated at 106 M ha (Derpsch and Friedrich, 2009). It was originally estimated to be 125 M ha for 2010/11 (Friedrich *et al.*, 2012), but it was found that the total global CA cropland area in 2010/11 was approximately 145 M ha during the 2013 database update.

The total global CA crop area was originally projected to be 155 M ha for 2013 (Kassam *et al.*, 2014b), but since then it has been reported to be 157 million hectares due to an increase in CA area in Argentina that was not reported at the time of the 2013 update (see http:/www.fao.org/ag/ca/6c.html) database (FAO, 2014b). CA is performed on soils ranging from 90 percent sand (e.g., Australia) to 80 percent clay (e.g., Brazil's Oxisols and Alfisols) and soils with a high content of clay in Brazil are highly sticky, but this has not been an obstacle to non-late adoption when equipment is available. Under tillage farming, soils that are readily prone to crusting and surface sealing do not present this problem under CA, because the mulch cover prevents crust formation. CA has even allowed agricultural expansion to marginal soils with respect to rainfall or fertility (e.g., Australia, Argentina). Zer o-tillage is practiced on all farm sizes from less than half a hectare to a few hectares (for example, China, Zambia, and Paraguay) to thousands of hectares (for example, Argentina, Brazil, and Kazakhstan). The CA description is quantified as follows for data collection:

• **No or minimum mechanical soil disturbance:** Minimum soil disturbance refers to no-tillage and direct seeding at low disturbance and the disturbed area must be less than 15 cm wide or less than 25 per cent (whichever is lower) of the cropped area. No frequent tillage should be allowed to disturb a greater area than the above limits and strip tillage is allowed when the area being disturbed is less than the set limit.

• **Organic soil cover:** There are three distinct categories: 30-60%, > 60-90% and > 90% ground cover, measured immediately after the direct seeding operation. Area with coverage of less than 30 per cent is not considered to be CA.

• **Crop rotation/association:** Rotation / association may include 3 different crops or more, nevertheless, for this data collection purpose repetitive wheat, maize or rice cropping is not an exclusion factor, but where practiced, rotation / association is registered.

Tillage

Adoption of various farming systems can have either positive or negative effects on physico-chemical and microbiological properties of soils. Conventional tillage can be characterized as a system based on synthetic fertilizers, pesticides and heavy tillage, a traditional production method that has led to soil degradation and reduced soil quality affecting the soil's ability to sustain food production (Schmitz *et al.*, 2015). In comparison, zero-tillage or conservation tillage attempts to follow natural processes which tend to improve soil and plant health while preserving soil and water resources (Gomiero *et al.* 2011) and decreases soil erosion, leaching of fertilizers, pesticides and herbicides into the ground water. Conservation and conventional tillage have a significant impact on bulk density and soil aggregation, and ZT improves soil micro flora activity, but some studies have shown higher soil microbial activity due to better aeration with conventional tillage.

Numerous studies performed in temperate climatic zones found that no-tillage resulted in acidification of the surface layer as compared to conventional tillage, persisted for several years. Conservation tillage increases the rate of soil infiltration and decreases soil evaporation thereby increasing soil water storage and raising soil organic carbon content due to higher residues in surface soil under ZT. Continuous application of organic materials / residues has been documented to improve soil physical conditions through increased aggregation and stabilization of the structure (Sheng *et al.*, 2012) due to reduced bulk density (Caravaca *et al.*, 2002) along with better soil fertility (Yadav *et al.*, 2013). Thus, from the literature, the zero-tillage practices appeared extremely important and superior to traditional tillage practices for increasing soil fertility and maintaining environmental sustainability. The effect of conservation and traditional tillage practices on soil quality was therefore studied at different districts of Haryana under different crop rotations and soil types.

Soil Physical Property

Bulk density

Hati *et al.* (2014) observed increased soil bulk density at the sub-surface layer with different crop rotations under conservation agriculture. Decreased bulk density at surface layer may be due to addition of organic matter as a source of plant nutrients but the literature available on the effect of conservational tillage on soil bulk density is controversial. Kumar *et al.* (2018) reported that bulk density was significantly affected by ZT and CT tillage practice and highest BD under ZT at surface layer compared to CT might be due to natural reconsolidation of soil particles because of subsequent irrigation and summer drying while Asenso *et al.* (2018) attributed greatest increase in BD under ZT treatment at 0-40 cm depth to undisturbed soil under ZT. The length of the study may also be a factor in the differing reports on no-till effect on BD since there have been long-term studies that reported lower bulk density under ZT. The soil bulk density can change in time, but not necessarily in a consistent tendency.

Soil Chemical properties

Electrical conductivity

Various chemical properties of soil under different cropping pattern were studied to find the impact of conservation tillage. Roldan *et al.* (2005) observed that electrical conductivity (EC) was not affected by the tillage practices while in contrast, Khan *et al.* (2017) reported increased EC under NT that might be due to minimized leaching of nutrients along with water and enhanced nutrients availability under NT. Non-significant effect of ZT or CT was observed in loam sand and sandy loam soil by Singh *et al.* (2015) but in contrast of these results Gholami, *et al.* (2014) reported that ZT had highest EC value compared to CT because lower electrical conductivity of soil under the ZT system compared to CT pertained to the enhanced water movement in the soil that improved soil aggregate development. Kumar *et al.* (2018) observed decreased soil EC under CT that might be due to opening and aeration of the top soil layers which allowed increased leaching to occur at surface soil.

Soil pH

Numerous studies conducted in temperate climate zones showed that no-tillage resulted in acidification of surface layer when continued for several years. Asenso *et al.* (2018) observed no significant difference on soil pH at 0–40 cm depth under zero-tillage that might be due to the fact that no limning material was applied as part of treatment. In contrast Kumar *et al.* (2018) reported significant effect of tillage on soil pH and highest pH was recorded in zero tillage at surface layer compared to conventional tillage system, this might be that the experiment was continuing from several years as a part of long term on dry land agriculture. Tillage may not directly affect soil pH but its effects on pH will depend on the prevailing climatic condition, soil type and management factors. The different soil texture as well as climatic conditions at different locations under present study authenticate our results.

Calcium carbonate content

The calcium carbonate ($CaCO_3$) content of different soil samples was affected by different crop rotations under conventional and zero-tillage to different extent, and similar findings have been reported in literature also. Celik *et al.* (2017) observed that calcium carbonate content of the soil was not significantly different within 0-30 cm depth, may be due to the tillage practices did not cause to accumulate calcium carbonate content within 30 cm of the soil surface. Reduction of Ca content in the tillage practices reported by Nta *et al.* (2017) can be explained due to the rapid breakdown and mineralization in soil organic carbon in mechanically tilled plot.

Distribution of nutrients in the soil

Conservational tillage at different locations was found to affect total N, P and K content under different crop-rotations varying in soil texture and higher total N, P and K content was observed under ZT system. Greater availability of total N, P and K content associated with the conservational tillage at surface layer is closely related to SOM build up as reported elsewhere.

Available N, P, K and S content was observed relatively higher under ZT in different textured soil at 0-15 cm depth in different districts of Haryana and similar observations have been reported by Kaushik *et al.* (2018) explained higher available N, P, K and S content under zero-tillage than CT because of more addition of crop residues and less disturbances of soil, increased P solubilisation and reduced P fixation of applied phosphorus, removal of potash by the crops under zero tillage system and higher addition of crop residue in zero tillage which resulted more build up of organic carbon, respectively, under zero tillage than conventional tillage. Urmila *et al.* (2018) also reported that stratification of crop residues and organic matter caused higher N, P, K and S contents at surface layer under ZT.

Soil Organic Matter (SOM)

Soil organic carbon (SOC) is an important indicator of soil health and SOC was higher in surface layer under ZT than conventional tillage (CT) and Song *et al.* (2019) that conservation tillage practices significantly influence the total soil organic carbon (SOC) content at surface (0-15 cm) layer compared to CT due to retention of residues, minimum disturbance and to accumulate organic carbon near the soil surface layer in ZT. Asenso *et al.* (2018) reported highest organic C under ZT at 0–40 cm depth that may be due to the undisturbed land resulting an increased buildup of soil organic matter which reflected a reduced rate of leaching in the soil surface profile. The results are also supported by the observations of other workers (Hati *et al.,* 2014; Jat *et al.*, 2018; Kaushik *et al.,* 2018; Kumar *et al.*, 2018; Zuber *et al.,* 2018). Effect of poultry manure and PSB culture with levels of phosphorus on growth and yield parameters viz. Plant height (cm), Number of leaves (plant-1), Number of branches (plant-1), Number of pods (plant-1) of Black gram was found significant. (Raisen and Swaroop, 2018).

Biological properties

An important aspect of tillage with respect to soil property is its effect on soil fauna activity. Among the aerobic organism, the fungi and aerobic bacteria increased with no-tillage as compared with conventional tillage.

Microbial biomass carbon and nitrogen

Soil microbial biomass is an indicator of microbial community *i.e* related to organic matter content of the soil. Microbial biomass carbon (MBC) and nitrogen (MBN) in different soil samples were affected by tillage and depth and relatively higher values were observed at surface layer. Kabiri *et al.*, 2015 and 2016 found that higher microbial biomass carbon and nitrogen contents under NT due to the increased SOM (C and N) level probably improved soil aggregation and higher microbial biomass content. In contrary, Zuber *et al.* (2018) found that rotation did not affect microbial biomass C and N (MBC, MBN) while conventional tillage reduced MBN at 10–20 cm compared to NT may be due to dispersion of N fertilizers throughout the soil and MBN was greater in NT than CT because of accumulation of SOM under no-tillage.

Enzymatic activities

Enzymes in soil are biologically significant as they influence the availability of plant nutrients and all microbial activities are directly related to the different enzymatic activities, which are released extracellularly by various microorganisms or plant roots. In soil, microorganisms, active roots and dead cells are the principal sources of enzymes. Soil enzymatic activity is a sensitive marker of the effect of ecological factors on microbial functions. In the present study, the effect of soil management practices under various crop-rotations at different locations on different enzymatic activities *viz.*

dehydrogenase, alkaline phosphatase, cellulase and urease was studied and activities of various enzymes were observed higher in 0-15 cm layer as compared to 15-30 cm layer.

Majchrzak *et al.*, 2016 and Bhaduri *et al.*, 2017 observed significant impact of tillage systems on DHA that was significantly higher under NT due to accumulation of organic matter and nutrients at the surface soil layer under no-tillage. The reason for higher alkaline phosphatase activity in surface layer may be due to high amount of inorganic phosphate released from organic matter under zero-tillage, resulting higher alkaline phosphatase activity at surface layer, the results are supported by the finding of that Mathew *et al.,* 2012 and Gajda *et al*., 2013.

Bini *et al.* (2014) reported that cellulase activity under no tillage was lower as compared with conventional tillage because of greater inputs of organic matter into the soil due to plowing and harrowing in CT, which made the organic C pools more prone to microbial and soil enzyme attacks. Raiesi and Kabiri (2016) observed higher urease activity reported under reduced tillage practices compared with CT practices may be due to high accumulation of soil organic carbon under no-tillage. In contrast, Asenso *et al.* (2018) found highest enzyme activities under subsoiling (SS) treatment compared to ZT treatments because SS treatment, loosened the soil and resulted higher organic C added into the soil, which increased the abundance of soil microorganisms resulting enhanced soil enzyme activities as a result of an increased substrate and oxygen availability.

Microbial count

Population of microbes in soil *viz.* bacteria, fungi, actinomycetes, *Azotobacter* and phosphate solublizing bacteria was observed higher in zero tilled soil at 0-15 cm depth compared to conventional tilled soil and bacteria were most abundant among all microbial groups under all systems. Dongre *et al.* (2017) attributed relatively higher bacterial, actinomycetes and fungal count at 0-15 cm depth under conservational agriculture system to submerged conditions in deeper layer. Schmidt *et al.* (2018) recorded higher total bacterial number in cover cropped plots at different depths, while no-till treatments showed higher number at surface layer compared to standard tillage because farming practices and depths favored distinctly different microbial life strategies.

Effect of tillage on nutrient release pattern of soil

Basal respiration is determined as a gross flux of CO_2 from mineralization that reflects the total metabolic activity of heterotrophic soil micro-organisms and labile carbon status of soil. C and N mineralization was higher under ZT system than CT system at surface layer under different crop-rotations. Fang *et al.* (2015) reported that significantly increased C and N mineralization at surface layer of NT can be due to decomposition of organic matter in surface layer. Higher mineral N was reported by Jat *et al.* (2018) under no-tillage because high C:N ratio stimulates the microbial community to degrade organic substrate. Kumar *et al.* (2018) reported that mineralizable nitrogen content increased at 0-15 cm depth under ZT as compared to conventional tillage and increased mineralizable nitrogen indicated higher accumulation of organic carbon due to retention of crop residue at surface soil.

Effect of tillage on functional diversity of micro-organisms

Community-level physiological profiling assesses the microbial community on the basis of sugar and amino acid utilization patterns and capacity to metabolize specific sole carbon sources. EcoPlate™ method can be used to study the variability of the community-level physiological profiling of microorganisms.

Habig and Swanepoel, (2015) reported that microbial diversity and activity were higher at surface layer under no-till than conventional tillage because the stimulation of soil microbial populations in no-tillage, promoted the availability of carbon sources for microbial utilization. Nivelle *et al.* (2016) found lowest AWCD and Shannon index under bare fallow and highest under cover crop-NT plots might be due to higher total nitrogen content and total organic carbon content that led to increased the diversity of substrate-richness and induced more microbial enzymes because of greater metabolism of phenolic compounds and carbohydrates (under no-till) and polymers (under conventional till) as carbon sources in plots under standard cover crop. In contrary to our results, Janušauskaite *et al.* (2013) found higher AWCD values under conventional tillage than no-tillage because higher availability of hydrocarbon sources in conventional tillage could promote microbial community’s diversity and increased use of carbon sources.

CONCLUSION

1. Although there were many early attempts to grow crops without tillage, modern zero-tillage work started in the 1940s, and farmers embraced it in the early 1960s.
2. The historical production of zero-tillage crop cultivation and the productive use in mechanized farms was closely linked to the following factors:

- Accessibility of adequate knowledge (research findings and experience of farmers) under various agro-ecological and socio-economic conditions
- The availability of a range of range of low cost effective herbicides
- The availability of suitable equipment at acceptable prices
- Application of appropriate crop rotations including green manure cover crops (this was

the basis for successful application in Latin America in particular)

3. Zero-tillage is neither a fashion nor a transitory trend, but a production system that is progressively spreading due to its obvious advantages and also due to environmental and economic pressures.

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