

Conservation agriculture for efficient resource use, sustainable crop production and better environment

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Conventional agriculture characterized by repetitive tillage, residue removal/burning and mono-cropping is responsible for a plethora of problems including yield stagnation, degradation of soil and water quality, and environmental pollution. Conservation agriculture, a paradigm shift from conventional farming brings sustainability to the production system with enhanced crop yields, reduced production costs, higher resource (nutrient, water, energy) use efficiency, and improved soil and environmental quality. Success of a conservation agriculture system relies upon implementation of all three basic principles, viz. zero tillage, residue retention and crop rotation in efficient and holistic manner.

Keywords: Conservation agriculture, Residue, Resource-use-efficiency, Sustainability, Zero tillage

GREEN Revolution during late 1960s and early 1970s has led to transformation to a food surplus India. Introduction of high-yielding varieties (HYVs), tractors and farm machinery, irrigation, and increased use of fertilizers and pesticides led to significant increase in productivity of rice and wheat in the north-western plain zone. This involved complete removal or burning of crop residues leading to almost clean cultivation, profuse tilling of land, fixed crop rotations mostly with cereals, and elimination of fertility-restorer crops like legumes. These unsustainable practices and over-exploitation of resources eventually led to a system fatigue giving rise to newer problems, viz. stagnating yield and farm income, soil erosion and declining nutrient bases, ground water depletion, accumulation of toxic substances in water and air, besides the concerns of climate change and global warming.

Conservation agriculture (CA) as described by FAO (<http://www.fao.org/ag/ca>) is a concept for resource saving agricultural crop production which aims at enhancing

Table 1. Characteristics differentiating conservation agriculture from conventional agriculture

Conventional agriculture	Conservation agriculture
"Business as usual" approach for yield maximization through more and inefficient use of resources	Optimizing yield and profit approach to achieve balanced agricultural, economic and environmental benefits.
Excessive tillage of soil through primary (mouldboard, disc) and secondary (cultivator, rotavator) implements for preparing a fine seed and root bed.	Seeds directly drilled into residue laden untilled soils using happy seeder, zero-till drill; reshaping of permanent beds preferably once in a year
Bare soil surface (residue burnt or removed)	Permanent soil cover (residue retention)
Ex-situ FYM/composts used	In-situ organics/composts used
Green manuring (incorporation)	Brown manuring/cover crops (retention)
Weed control by tillage, herbicides and other means	Weeds control before sowing by non-selective herbicides (glyphosate, paraquat, glufosinate) and after sowing by selective herbicides. Also using crop residue mulch and legume cover for suppressing weeds.
Increased soil compaction through free-wheeling of farm machinery	No compaction in cropped area but controlled traffic can have compaction in tramline
Monocropping/culture, less efficient rotations	Diversified and more efficient rotations
More reliance on manual labourers (e.g. puddled transplanted rice)	Mechanized operations such as dry direct-seeded rice.
Declining productivity in the long-run	Productivity improves with time
Lower organic matter and microbial diversity in soil	Higher organic matter and microbial diversity in soil
Poor soil physical properties (aeration, infiltration and aggregation)	Improved soil physical properties (aeration, infiltration and aggregation)

the natural and biological processes above and below the ground. It is characterized by three inter-linked and inter-related principles: (i) minimal soil disturbance (zero/minimal tillage), (ii) permanent soil cover (at least 30% area covered with residue), and (iii) diversified crop rotations including a legume. CA practices have potential to sustain crop production, reduce costs with concurrent increase in income as well as preserve soil and environmental quality. In India, CA is adopted in about 1.5-2.5 million ha, while zero tillage alone is practiced in a larger area of approximately 3.0-3.5 M ha. CA involves a paradigm shift in farming practices with regard to management of crops, soil, water, nutrients, weeds, and farm machinery, which are totally at variance with conventional agriculture (Table 1).

CA based technologies

Precision land leveling

Laser land levelling (LLL) is a pre-requisite for adopting CA practices. The problems of uneven slopes with conventional levelling lead to non-uniform seed placement and germination. This can be corrected by using laser land levelling, which levels the land surface within ± 2 cm of its average micro-elevation using a laser-equipped drag scrapper (Fig. 1). The LLL makes a smooth and graded field facilitating irrigation water to reach to the tail-end of the field in less time. Thus, it saves irrigation



Fig. 1. Laser land leveler.

water by 15-20%, and increases net area sown by 3-4% due to fewer bunds and channels required. Crop yields increase by 4-5% due to uniform seedling emergence, better crop stand, and early crop vigour. It improves input-use (water and nutrient) efficiency and reduces labour requirement. Farmers can use this machine on custom-hiring basis which is now easily available in most areas.

Zero tillage with residue

Zero tillage (ZT) involves sowing of crop in untilled soils by using a specially-designed ZT seed-cum-fertilizer drill (Fig. 2). Happy seeder consists of straw chopper and ZT

drill, which can effectively operate in untilled fields with standing and loose stubble. ZT sowing can be adopted successfully in most crops like wheat, direct-seeded rice (DSR), soybean, clusterbean, pigeonpea, mungbean, pearl millet, chickpea, mustard and lentil (Fig. 3). By adopting this technique, wheat sowing after rice can be advanced by 15-20 days, and yield losses caused by late sowing can be avoided. It saves cost by around ₹ 4,000-5,000/ha for tillage and gives 15-20% higher yield of wheat. Besides, wear and tear losses of tractor and machinery are minimized. Water requirement is reduced and weed infestation is also reduced over time.



Fig. 2. Zero-till sowing under residue in wheat (a) and rice (b).

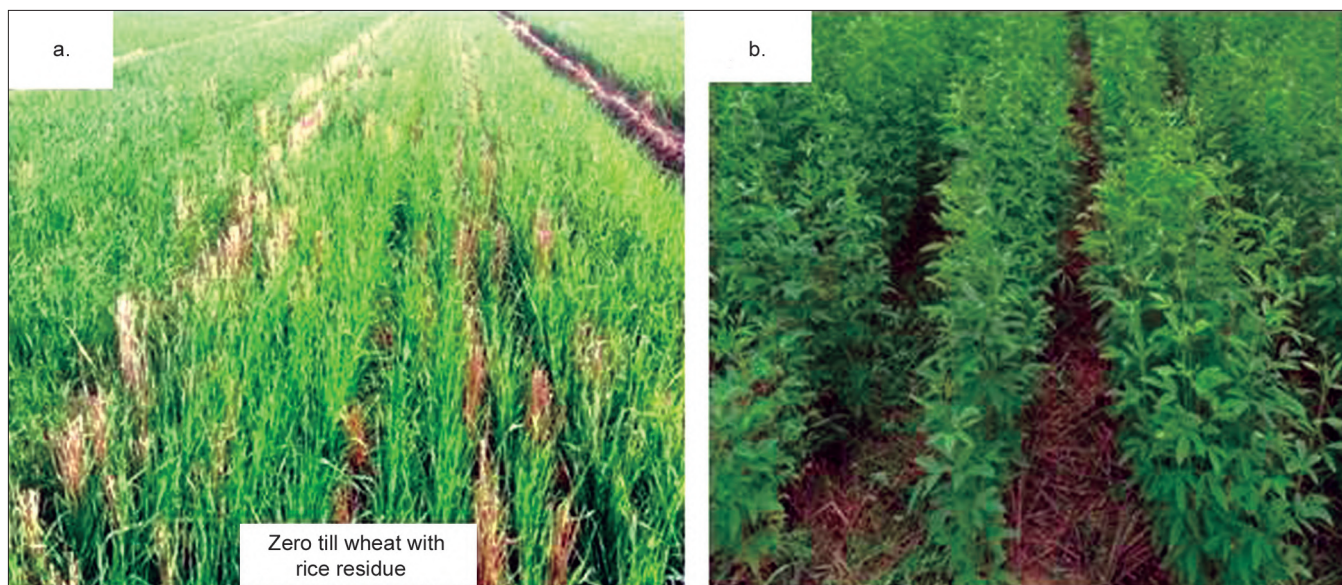


Fig. 3. Growth of wheat (a) and pigeonpea (b) under zero-till + residue.

For controlling existing weeds, non-selective herbicide like paraquat or glyphosate may be applied at 0.5-1.0 kg/ha before sowing. Crop residues/stubbles or other vegetative material should be retained on soil surface under ZT conditions to reduce compaction of soil. This will lead to favorable effect on root development.

Bed planting with residue

Bed planting involves sowing of crops using raised-bed planter alternated with furrows for irrigation. Bed width depends upon crop spacing usually ranging from 60-100 cm, and accommodates 2-3 crop rows. Beds require reshaping each year preferably before *khari* season. Bed planting reduces cost, and saves seed, fertilizer and irrigation water. It also increases water-use efficiency both under rainfed and irrigated scenarios because water moves laterally from furrows into beds thereby reducing evaporation losses. The furrow

irrigated raised-bed system (FIRBS) of wheat has been reported to save seed and water by 25-40% and fertilizer by 25%, with similar wheat yields (Fig. 4). Further, lodging of wheat is lower owing to lesser physical contact of wheat culms with irrigation water, as well as better aeration within furrows. Weed population including problematic weed *Phalaris minor* is reduced on top of beds, thereby reducing cost of weeding and herbicide dependence. Bed planting facilitates diversification of rice-wheat system with cotton, pigeonpea, maize, soybean, vegetables, sugarcane, etc. which can be sown/planted on beds using this technology.

Direct-seeded rice

Dry direct-seeded rice (DSR) is an alternative technique that requires less water and labour than traditional puddled-transplanted-flooded rice (Fig. 5). Rice seeds are mechanically

sown into tilled or untilled soil through suitable seed-cum-fertilizer drill and aerobic soil conditions are maintained throughout the growth period. DSR should be sown in first fortnight of June, using 20-30 kg/ha seeds at 20 cm row spacing. Direct seeding offers several advantages over puddled transplanted rice like saving irrigation water (20-30%), labour (40-45%), fuel (65-70) and seed, permits early planting and reduces emission of greenhouse-gases. With adoption of improved varieties supplemented with judicious nutrient, water and weed management, yields to the level of transplanted rice can be obtained. Furthermore, growth and establishment of succeeding *rabi* crop will be higher owing to better soil conditions compared to puddled rice.

Brown manuring with dhaincha

For brown manuring, rice and dhaincha (*Sesbania aculeata*) are

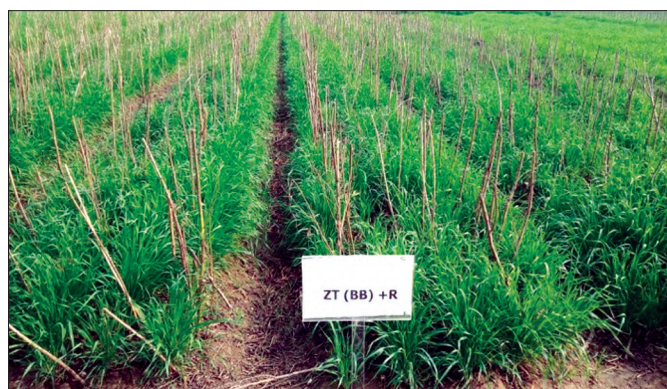


Fig. 4. Wheat under permanent broad-bed with pigeonpea residue.



Fig. 5. Zero-till direct-seeded rice.



Fig. 6. Brown manuring with dhaincha (after 2,4-D application) in direct-seeded rice.



Fig. 7. Zero-till summer mungbean with wheat residue.

grown together as co-culture for initial 25-30 days. Dhaincha at 25 kg/ha can be drilled together with DSR or alternatively can be broadcast on soil before/after rice sowing. Dhaincha develops thick canopy and biomass within 25-30 days, and thereafter selectively killed by using 2,4-D @ 0.50 kg/ha or bispiribac-Na @ 20-25 g/ha (Fig. 6). Dhaincha plants perform dual role of live and dead mulch leading to weed smothering and reduced herbicide usage in rice. Being a leguminous crop, it supplies 15-20 kg N/ha and 10-12 t/ha fresh biomass, thereby stimulating growth and yield of rice crop. Brown manuring also facilitates better emergence of rice under soil crusting, enhances moisture conservation with residue mulch, and improves soil carbon content. Brown manuring also can be practiced in maize crop for better weed management and profitability.

Crop diversification with summer mungbean

In North India conditions, cereal-cereal systems can be diversified by growing mungbean during summer fallow period for enhancing system productivity, profitability and soil health. Short-duration summer mungbean variety such as SML 668 can be sown after wheat in the first fortnight of April and harvested before sowing of rice crop in mid-June (Fig. 7). Mungbean can be mechanically sown through Zero till drill with 18-20 kg/ha seed rate and 20 cm spacing. Summer mungbean gives a seed yield of 8-10 q/ha and

adds 40-60 kg N/ha in soil, thereby reducing N requirement of the subsequent crop. It can also smother weeds and reduce cost of weeding in the succeeding crop.

CA impacts on productivity and net income

Long-term studies on CA at ICAR-IARI, New Delhi indicated that a triple Zero till (ZT) system with residue (Table 2) involving zero till direct seeded rice (ZTDSR) with summer mungbean (SMB) residue - ZT wheat (ZTW) with rice residue (RR) - ZT summer mungbean (SMB) with wheat residue (~MBR+ZT DSR - RR+ZTW-WR+SMB) resulted in higher system productivity (SP) and net returns (NR). This system gave higher system productivity by 9 q/ha and net returns by ₹ 67,000/ha over the conventional puddled transplanted rice - conventional-till wheat (TPR-CTW).

In non-rice based cropping system, broadbed (140 cm) planting was found more remunerative than conventional-till flat planting (Table 3). Cotton-wheat cropping system

realized 1.0-1.5 times more system productivity compared to that in pigeonpea-wheat and maize-wheat systems. Cotton-wheat cropping system under broad-bed system with residues of both the crops gave higher system productivity and net returns than that in the transplanted rice- conventional till wheat system. Inclusion of leguminous crop in cereal system (rice-wheat/maize-wheat) contributed an increase of 18% in system productivity and 15% in net returns.

CA impacts on resource-use efficiency

Adoption of CA practices has shown tremendous potential to deal with the problems of declining ground-water table, and improved nutrient, water and energy-use efficiency. ZTDSR saved 22-40% of irrigation water and 13-34% energy inputs over transplanted rice (TPR). Likewise, diversification of TPR with maize under CA-based management reduced the irrigation water demand by 89% and energy use by 66%. At IARI, New Delhi 30-35% saving in irrigation water and 91% higher system water productivity (kg grain/

Table 2. System productivity and net returns in rice-based cropping system with CA practices

Treatment	Rice equivalent yield (t/ha)	Net returns (₹/ha x 10 ³)
ZT DSR - ZTW	9.76	159.8
WR+ZT DSR - RR+ZTW	11.27	166.9
WR+ZTDSR+BM- RR+ZTW	8.94	121.1
ZT DSR - ZTW - ZT SMB	10.07	193.6
MBR + ZT DSR - RR+ZTW -WR+ ZT SMB	11.50	225.5
TPR-CTW	10.62	158.2

ZTW- Zero till wheat; RR- Rice residue; BM- Brown manuring; WR- Wheat residue; MBR- Mungbean residue; TPR- Transplanted puddled rice; CTW- Conventional till wheat

Table 3. System productivity (in wheat equivalent yield) and net returns in different CA-based systems

Cropping system	Wheat equivalent yield (t/ha)	Net returns (₹/ha x 10 ³)
Maize-wheat (zero till-broad bed)+crop residue	7.99	59.79
Pigeonpea-wheat (zero till-broad bed)+crop residue	9.83	84.38
Cotton-wheat (zero till-broad bed)+crop residue	14.67	122.72
Mungbean residue+DSR - zero-till wheat + rice residue-mungbean	11.78	113.90
Transplanted rice- conventional till wheat	11.40	94.16

Table 4. Irrigation water productivity under different zero-till cropping systems

Cropping system	Total irrigation water (ha-mm)		Irrigation water productivity (kg wheat/ha-mm)	
	Kharif	Rabi	Kharif	Rabi
<i>Maize-wheat</i>				
Zero till- bed planting	150	250	22.67	20.40
Conventional till flat planting	210	350	12.57	14.69
<i>Pigeonpea-wheat</i>				
Zero till-bed planting	350	250	15.00	19.72
Conventional till flat planting	490	350	7.67	13.89
<i>Cotton-wheat</i>				
Zero till-bed planting	550	250	16.93	19.40
Conventional till flat planting	770	350	9.00	13.86

m³ of water) was reported from the triple ZT rice-wheat-mungbean system. Diversification with cotton-wheat, pigeonpea-wheat and maize-wheat systems resulted in 60.3, 67.9 and 63.5% savings in irrigation water, 49.4, 56.1 and 58.7% savings in total water and 215.4, 172.5 and 150.8% higher SWP, respectively compared to TPR-CTW system. Zero-till bed planting gave higher irrigation water productivity over conventional flat planting (Table 4). CA-based rice-wheat-mungbean systems improved system productivity by 11%, profitability by 24% with 28% less irrigation water and 25% less energy input compared to conventional RW system. Maize planted on permanent beds with retention of crop residues resulted in 16% higher water productivity and 11% saving in irrigation water compared to the flat system.

CA impacts on soil health and environment

CA practices reverse soil degradation caused by conventional tillage by improving soil physical, chemical, and biological properties. These systems also have lower environmental footprint by using less irrigation water, energy and reducing global warming potential. CA

showed favourable impact on soil bulk density, penetration resistance, saturated hydraulic conductivity, soil aggregation and root-length density at IARI, New Delhi. The bulk density was significantly reduced in DSR, particularly in DSR - ZTW compared to TPR - ZTW. The triple ZT system i.e. mungbean residue + DSR - ZTW + rice residue - summer mungbean + wheat residue resulted in 13% higher total soil organic carbon than conventional rice-wheat in the 0-5 cm soil layer. By adopting CA with residue retention for long-term, 30 and 50% reduction in N and K dose respectively was achieved in wheat without affecting yield levels. A shift from CTTPR to ZT-DSR can reduce methane emissions

by <50-55% and global warming potential by 30-35%.

SUMMARY

Conservation agriculture is an innovative, highly efficient production system which promotes natural resource conservation together with lower production costs, improved soil health, and reduced environmental pollution and global warming potential. Application of three inter-linked principles of CA, viz. minimal soil disturbance, continuous residue cover, and crop diversification/ rotation should be used together for attaining maximum benefits. In India, adoption of CA has enormous scope with availability of adequate ZT machinery backed up with favourable policy support. The issues related to be addressed are competition for crop residues, allelopathic effects, nematode and soil-borne insect/pathogen problems under residue, changing weed dynamics for promotion of CA through strategic planning and efficient management. Shift from conventional to conservation agriculture is a challenging task towards attaining sustainability in production systems and aligning agriculture in harmony with nature.

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