

# Crop Residues Management with Conservation Agriculture: Potential, Constraints and Policy Needs



Indian Agricultural Research Institute  
Indian Council of Agricultural Research  
New Delhi-110012



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*Crop Residues Management with Conservation Agriculture: Potential, Constraints and Policy Needs*

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## Foreword

India being an agriculture-dominant country produces more than 500 million tons of crop residues annually. These residues are used as animal feed, for thatching of homes, and as a source of domestic and industrial fuel. A large portion of unused crop residues are burnt in the fields primarily to clear the left-over straw and stubbles after the harvest. Non-availability of labour, high cost of residue removal from the field and increasing use of combines in harvesting the crops are main reasons behind burning of crop residues in the fields. Burning of crop residues causes environmental pollution, is hazardous to human health, produces greenhouse gases causing global warming and results in loss of plant nutrients like N, P, K and S. Therefore, appropriate management of crop residues assumes a great significance.

Recent research efforts have developed conservation agriculture-based crop management technologies which are more resource-efficient than the conventional practices. The conservation agriculture practices can make efficient use of crop residues. However, information about their use is scanty. This bulletin will fill the gap and will generate awareness about such technologies. The bulletin provides comprehensive information about the generation of crop residues every year in the country and the extent of their on-farm burning along with their environmental impacts. It is perhaps the first attempt in the country towards identification of the competing uses of crop residues and suggesting their management options gainfully. The bulletin has also mentioned the research and policy issues related to their safe and sustainable management at local and regional scales.

I appreciate the efforts of the authors in bringing out this important bulletin and do hope that it will generate interest of the students, researchers, policymakers and farmers towards efficient management of crop residues in the country.

A handwritten signature in black ink, appearing to read 'H.S. Gupta', with a horizontal line underneath.

**(H.S. Gupta)**

Director

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## Abbreviations

CA	Conservation agriculture
CEC	Cation exchange capacity
CESCRA	Center for Environment Science and Climate Resilient Agriculture
CIAE	Central Institute of Agricultural Engineering
CRIDA	Central Research Institute for Dryland Agriculture
CSISA	Cereal Systems Initiative for South Asia
FAO	Food and Agriculture Organization
FYM	Farmyard manure
GHGs	Greenhouse gases
IGP	Indo-Gangetic Plains
IPCC	Inter-Governmental Panel on Climate Change
IPM	Integrated pest management
KPTL	Kalpataru Power Transmission Limited
KVIC	Khadi Village Industries Commission
KVK	Krishi Vigyan Kendra
MNRE	Ministry of New and Renewable Energy
Mt	Million tons
NGOs	Non-Governmental Organizations
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
RCTs	Resource conserving technologies
SPRERI	Sardar Patel Renewable Energy Research Institute
SVOCs	Semi-volatile organic compounds
VOCs	Volatile organic compounds

# Crop Residues Management with Conservation Agriculture: Potential, Constraints and Policy Needs

## Introduction

India is an agrarian economy. A vast majority of land is used for farming and a wide range of crops are cultivated in its different agro-ecological regions. With a production of 93.9 million tons (Mt) of wheat, 104.6 Mt of rice, 21.6 Mt of maize, 20.7 Mt of millets, 357.7 Mt of sugarcane, 8.1 Mt of fibre crops (jute, mesta, cotton), 17.2 Mt of pulses and 30.0 Mt of oilseeds crops, in the year 2011-12 (MoA, 2012), it is but natural that a huge volume of crop residues are produced both on-farm and off-farm. It is estimated that approximately 500-550 Mt of crop residues are produced per year in the country. These crop residues are used for animal feeding, soil mulching, bio-manure making, thatching for rural homes and fuel for domestic and industrial use. Thus crop residues are of tremendous value to the farmers. However, a large portion of the residues is burnt on-farm primarily to clear the field for sowing of the succeeding crop. The problem of on-farm burning of crop residues is intensifying in recent years due to shortage of human labour, high cost of removing the crop residues by conventional methods and use of combines for harvesting of crops. The residues of rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut are typically burnt on-farm across different states of the country. The problem is more severe in the irrigated agriculture, particularly in the mechanized rice-wheat system of the northwest India (Fig. 1).



*Fig. 1. Burning of rice residues, a prevalent practice in northwest India*

It is a paradox that burning of crop residues and scarcity of fodder coexists in this country, leading to significant increase in prices of fodder in recent years. Industrial demand for crop residues is also increasing. To manage the residues in a productive and profitable manner, conservation agriculture (CA) offers a good promise. With the adoption of conservation agriculture-based technologies these residues can be used for improving soil health, increasing crop productivity, reducing pollution and enhancing sustainability and resilience of agriculture. The resource conserving technologies (RCTs) involving no or minimum tillage, direct seeding, bed planting and crop diversification with innovations in residues management are the possible alternatives to the conventional energy and input-intensive agriculture.

The gravity of the situation demands that an appropriate policy should be evolved to promote multiple uses of crop residues in the context of conservation agriculture and to prevent their on-farm burning. Under this scenario this bulletin aims to (i) quantify the amount of crop residues generated in the country every year and the extent of their on-farm burning, (ii) assess the environmental impacts of on-farm burning of crop residues, (iii) identify competing uses of crop residues and their adoption potential, (iv) assess the potential of using crop residues for conservation agriculture and constraints

involved therein, (v) develop a model plan for managing crop residues at the local and regional scales, and (vi) identify research and policy issues for safe and sustainable management of crop residues for productive, profitable and sustainable agriculture.

## Generation of crop residues in India

The Ministry of New and Renewable Energy (MNRE, 2009), Govt. of India has estimated that about 500 Mt of crop residues are generated every year (Table 1). There is a wide variability in the generation of crop residues and their use across different regions of the country depending on the crops grown, cropping intensity and productivity of these crops. The generation of crop residues is highest in Uttar Pradesh (60 Mt) followed by Punjab (51 Mt) and Maharashtra (46 Mt). Among different crops, cereals generate maximum residues (352 Mt), followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt) and sugarcane (12 Mt) (Fig. 2). The cereal crops (rice, wheat, maize, millets) contribute 70% while rice crop alone contributes 34% to the crop residues (Fig. 2). Wheat ranks second with 22% of the crop residues whereas fibre crops contribute 13% to the crop residues generated from all crops. Among fibres, cotton generates maximum (53 Mt) with 11% of crop residues. Coconut ranks second among fibre crops with generation of 12 Mt of residues. Sugarcane residues comprising of tops and

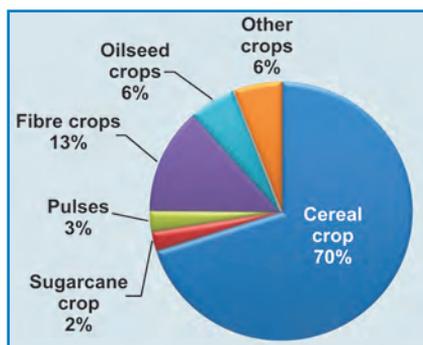


Fig. 2. Residue generation by different crops in India (calculated from MNRE, 2009)

leaves, generate 12 Mt, i.e., 2% of the crop residues in India. Generation of crop residues of cereals is also highest in Uttar Pradesh (53 Mt), followed by Punjab (44 Mt) and West Bengal (33 Mt). Maharashtra contributes maximum to the generation of residues of pulses (3 Mt) while residues from fibre crops are dominant in Andhra Pradesh (14 Mt). Gujarat and Rajasthan generate about 6 Mt each of residues from oilseed crops.

## **Utilization and on-farm burning of crop residues in India**

The utilization of crop residues varies across different states of the country. Traditionally crop residues have numerous competing uses such as animal feed, fodder, fuel, roof thatching, packaging and composting. The residues of cereal crops are mainly used as cattle feed. Rice straw and husk are used as domestic fuel or in boilers for parboiling rice. Farmers use crop residues either themselves or sell it to landless households or intermediaries, who further sell them to industries. The remaining residues are left unused or burnt on-farm. In states like Punjab and Haryana, where crop residues of rice are not used as cattle feed, a large amount is burnt on-farm. Sugarcane tops are either used for feeding of dairy animals or burnt on-farm for growing a ratoon crop in most parts of the country. Residues of groundnut are burnt as fuel in brick kilns and lime kilns. The residues of cotton, chilli, pulses and oilseed crops are mainly used as fuel for household needs. The shells of coconut, stalks of rapeseed and mustard, pigeon pea and jute and mesta, and sunflower are used as domestic fuel.

The surplus residues i.e., total residues generated minus residues used for various purposes, are typically burnt on-farm. Estimated total amount of crop residues surplus in India is 91-141 Mt. Cereals and fibre crops contribute 58% and 23%, respectively (Fig. 3) and remaining 19% is from sugarcane, pulses, oilseeds and other crops. Out of 82 Mt surplus residues

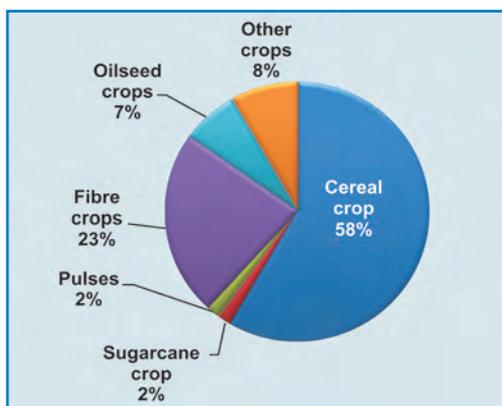


Fig. 3. The share of unutilized residues in total residues generated by different crops in India (calculated from MNRE, 2009)

from the cereal crops, 44 Mt is from rice followed by 24.5 Mt from wheat, which is mostly burnt on-farm (Table 1). In case of fibre crops (33 Mt of surplus residue) approximately 80% of the residues are from cotton and are subjected to on-farm burning.

**Table 1: State-wise generation and remaining surplus of crop residues in India**

State	Crop residues generation (MNRE, 2009)	Crop residues surplus (MNRE, 2009)	Crop residues burnt (based on IPCC coefficients)	Crop residues burnt (Pathak et al. 2010)
Mt yr <sup>-1</sup>				
Andhra Pradesh	43.89	6.96	6.46	2.73
Arunachal Pradesh	0.40	0.07	0.06	0.04
Assam	11.43	2.34	1.42	0.73
Bihar	25.29	5.08	3.77	3.19
Chhattisgarh	11.25	2.12	1.84	0.83
Goa	0.57	0.14	0.08	0.04
Gujarat	28.73	8.9	9.64	3.81
Haryana	27.83	11.22	6.06	9.06

State	Crop residues generation (MNRE, 2009)	Crop residues surplus (MNRE, 2009)	Crop residues burnt (based on IPCC coefficients)	Crop residues burnt (Pathak et al. 2010)
Himachal Pradesh	2.85	1.03	0.20	0.41
Jammu and Kashmir	1.59	0.28	0.35	0.89
Jharkhand	3.61	0.89	1.11	1.10
Karnataka	33.94	8.98	3.05	5.66
Kerala	9.74	5.07	0.40	0.22
Madhya Pradesh	33.18	10.22	3.74	1.91
Maharashtra	46.45	14.67	7.82	7.41
Manipur	0.90	0.11	0.14	0.07
Meghalaya	0.51	0.09	0.10	0.05
Mizoram	0.06	0.01	0.02	0.01
Nagaland	0.49	0.09	0.11	0.08
Odisha	20.07	3.68	2.61	1.34
Punjab	50.75	24.83	9.84	19.62
Rajasthan	29.32	8.52	3.84	1.78
Sikkim	0.15	0.02	0.01	0.01
Tamil Nadu	19.93	7.05	3.62	4.08
Tripura	0.04	0.02	0.22	0.11
Uttarakhand	2.86	0.63	0.58	0.78
Uttar Pradesh	59.97	13.53	13.34	21.92
West Bengal	35.93	4.29	10.82	4.96
<b>India</b>	<b>501.76</b>	<b>140.84</b>	<b>91.25</b>	<b>92.81</b>

It is worth mentioning here that large uncertainties as well as variability exist in the estimates of generation, utilization and on-farm burning of crop residues. Pathak et al. (2004) had estimated that annually 523 Mt crop residues were generated in India, out of which 127 Mt was surplus. According to MNRE (2009), the amount of crop residues generated was 500 Mt and surplus was 141 Mt (Table 1). Crop-wise the annual

surplus crop residues of cotton stalk, pigeon pea stalk, jute and mesta, groundnut shell, rapeseed and mustard and sunflower were estimated to be 11.8 Mt, 9.0 Mt, 1.5 Mt, 5.0 Mt, 4.5 Mt, and 1.0 Mt, respectively. According to the estimates of Sardar Patel Renewable Energy Research Institute (2004), about 72 Mt crop residues are burnt on-farm. Recently, Pathak et al. (2010) have estimated that about 93 Mt of crop residues are burnt on-farm in the country.

## **Adverse consequences of on-farm burning of crop residues**

Burning of crop residues leads to release of soot particles and smoke causing human and animal health problems. It also leads to emission of greenhouse gases namely carbon dioxide, methane and nitrous oxide, causing global warming and loss of plant nutrients like N, P, K and S. The burning of crop residues is wastage of valuable resources which could be a source of carbon, bio-active compounds, feed and energy for rural households and small industries. Heat generated from the burning of crop residues elevates soil temperature causing death of active beneficial microbial population, though the effect is temporary, as the microbes regenerate after a few days. Repeated burnings in a field, however, diminishes the microbial population permanently. The burning of crop residues immediately increases the exchangeable  $\text{NH}_4^+$ -N and bicarbonate- extractable P content, but there is no build up of nutrients in the profile. Long-term burning reduces total N and C, and potentially mineralizable N in the upper soil layer.

The burning of agricultural residues leads to significant emissions of chemically and radiatively important trace gases such as methane ( $\text{CH}_4$ ), carbon monoxide (CO), nitrous oxide ( $\text{N}_2\text{O}$ ), oxides of nitrogen ( $\text{NO}_x$ ) and sulphur ( $\text{SO}_x$ ) and other hydrocarbons to the atmosphere. About 70%, 7% and 0.7% of C present in rice straw is emitted as carbon dioxide, carbon monoxide and methane, respectively, while 2% of N in straw is emitted as nitrous oxide upon burning. It also emits a large

amount of particulates that are composed of a wide variety of organic and inorganic species. One ton of rice straw on burning releases about 3 kg particulate matter, 60 kg CO, 1460 kg CO<sub>2</sub>, 199 kg ash and 2 kg SO<sub>2</sub> (Gadi, 2003). Besides other light hydrocarbons, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), SO<sub>x</sub> and NO<sub>x</sub> are also emitted. These gases are of major concern for their global impact and may lead to increase in the levels of aerosols, acid deposition, increase in tropospheric ozone and depletion of the stratospheric ozone layer. These may subsequently undergo trans-boundary migration depending upon the wind speed/direction, reactions with oxidants like OH<sup>·</sup>, leading to physico-chemical transformation and eventually wash out by precipitation. Many pollutants found in large quantities in biomass smoke are known or suspected carcinogens and could be a major cause of concern leading to various air-borne/lung diseases.

### **Reasons behind on-farm burning of crop residues**

Farmers and policy makers are well-aware of the adverse consequences of on-farm burning of crop residues. However, because of increased mechanization, particularly the use of combine harvesters, declining numbers of livestock, long period required for composting and unavailability of alternative economically viable solutions, farmers are compelled to burn the residues. The number of combine harvesters in the country, particularly in the Indo-Gangetic Plains (IGP) has increased dramatically from nearly 2000 in 1986 to over 10000 in 2010. The north-western part (Punjab, Haryana and Western Uttar Pradesh) of the IGP has about 75% of the cropped area under combine harvesting. Combine harvesters are used extensively in the central and eastern Uttar Pradesh, Uttarakhand, Bihar, Rajasthan, Madhya Pradesh and in the southern states as well for harvesting rice and wheat crops. Major reasons for rapid increase in the use of combines are labour shortage, high wages during harvesting season,

ease of harvesting and thrashing and uncertainty of weather. On using combine harvesting; about 80% of the residues are left in the field as loose straw that finally ends up being burnt on farm.

There are some other reasons also behind intentional burning of crop residues. These include clearing of fields, soil fertility enhancement, and pest and pasture management. On farm burning traditionally provides a fast way to clear the fields off the residual biomass, thus, facilitating land preparation and sowing/planting. It also provides a fast way of controlling weeds, insects and diseases, both by eliminating them directly or by altering their natural habitat. The time gap between rice harvesting and wheat sowing in north-west India, for example, is only 15-20 days. In this short duration, farmers prefer to burn the rice straw on-farm instead of harvesting it for fodder or any other use. The latter options also involve a huge transportation cost. On-farm burning is also perceived to boost soil fertility, although burning actually has a differential impact on soil fertility. It increases the short-term availability of some nutrients (for example P and K) and reduces soil acidity, but ultimately leads to a loss of other nutrients (for example N and S) and organic matter.

## **Competing uses of crop residues**

The crop residues can be gainfully utilized for livestock feed, composting, power generation, biofuel production and mushroom cultivation besides several other uses like thatching, mat-making and toy making.

### *Livestock feed*

In India, the crop residues are traditionally utilized as animal feed as such or by supplementing with some additives. However, crop residues, being unpalatable and low in digestibility, cannot form a sole ration for livestock. Crop residues are low-density fibrous materials, low in nitrogen, soluble carbohydrates, minerals and vitamins with varying

amounts of lignin which acts as a physical barrier and impedes the process of microbial breakdown. To meet the nutritional requirements of animals, the residues need processing and enriching with urea and molasses, and supplementing with green fodders (leguminous/non-leguminous) and legume (sunhemp, horse gram, cowpea, gram) straws.

### *Compost making*

The crop residues have been traditionally used for preparing compost. For this, crop residues are used as animal bedding and are then heaped in dung pits. In the animal shed each kilogram of straw absorbs about 2-3 kg of urine, which enriches it with N. The residues of rice crop from one hectare land, on composting, give about 3 tons of manure as rich in nutrients as farmyard manure (FYM). Indian Agricultural Research Institute (IARI), New Delhi, has successfully developed a biomass-compost unit for making of good quality compost. This mechanized unit efficiently uses waste biomass and crop residues generated in the IARI farm. The decomposition process, which is hastened by a consortium of microorganisms, takes 75-90 days. During the year 2010-11, the unit prepared about 4000 tons of compost and in the subsequent year it increased to over 5000 tons (S.D. Mishra, personal communication).

### *Energy source*

Biomass can be efficiently utilized as a source of energy and is of interest worldwide because of its environmental advantages. In recent years, there has been an increase in the usage of crop residues for energy generation and as substitute for fossil fuels. In comparison with other renewable energy sources such as solar and wind, biomass source is storable, inexpensive, energy-efficient and environment-friendly. However, straw is characterized by low bulk-density and low energy yield per unit weight basis. The logistics for transporting large volumes of straw required for efficient energy generation represents a major cost factor irrespective



*Fig. 4. Preparation of improved quality compost from crop residues  
(Courtesy: S.D. Mishra, IARI, New Delhi)*

of the bio-energy technology. Availability of residues, transportation cost and infrastructural settings (harvest machinery, modes of collection, etc.) are some of the limiting factors of using residues for energy generation.

Kalpataru Power Transmission Limited (KPTL), a leading global engineering, procurement and construction player in power sector, is successfully generating energy from crop residues in Ganganagar and Tonk districts of Rajasthan for the past several years. At Tonk, the plant utilizes 80,000 tons of biomass, mostly from mustard crop, annually and generates 1.5 lakh kWh energy per day (Fig. 5). However, the plant produces a large amount of bio-ash requiring its management in a profitable manner.

### *Bio-fuel and bio-oil production*

Conversion of ligno-cellulosic biomass into alcohol is of immense importance as ethanol can either be blended with gasoline as a fuel extender and octane-enhancing agent or used as a neat fuel in internal combustion engines. Theoretical estimates of ethanol production from different feedstock (corn grain, rice straw, wheat straw, bagasse and saw dust) vary from 382 to 471 l t<sup>-1</sup> of dry matter. The technology of ethanol production from crop residues is, however, evolving in India. There are a few limiting steps in the process of conversion of

crop residues into alcohol, which need to be improved. High energy requiring operating conditions, costly hydrolytic cellulase enzyme, and unavailability of natural robust commercial organism to ferment pentose and hexose sugars simultaneously either as single species or in combination of other species are some of the constraints, which require additional research efforts.



*Fig. 5. Thermal plant of Kalpataru Power Transmission Limited producing energy from crop residues at Tonk, Rajasthan (Courtesy: N. Gupta, IARI, New Delhi)*

Bio-oil can be produced from crop residues by the process of fast pyrolysis, which requires temperature of biomass to be raised to 400-500 °C within a few seconds, resulting in a remarkable change in the thermal disintegration process. About 75% of dry weight of biomass is converted into condensable vapours. If the condensate is cooled quickly within a couple of seconds, it yields a dark brown viscous liquid commonly called bio-oil. The calorific value of bio-oil is 16-20 MJ kg<sup>-1</sup>.

### *Bio-methanation*

The process of bio-methanation utilizes crop residues in a non-destructive way to extract high quality fuel gas and produce manure to be recycled in soil. Biomass such as rice straw can be converted into biogas, a mixture of carbon dioxide and methane, which can be used as fuel. Biogas of 300 m<sup>3</sup> with 55-60% of methane can be obtained per ton of dry rice straw. The process also yields good quality spent slurry, which can be used as manure. This technology has been successfully demonstrated by various organizations such as IARI.

### *Gasification*

Gasification is a thermo-chemical process in which gas is formed due to partial combustion of crop residues. The main problem in biomass gasification for power generation is the purification of gas for removal of impurities. The crop residues can be used in the gasifiers for 'producer gas' generation. In some states, gasifiers of more than 1 MW capacity have been installed for generation of 'producer gas', which is fed into the engines coupled with alternators for electricity generation. One ton of biomass can produce 300 kWh of electricity. The gasification technology can be successfully employed for utilization of crop residues in the form of pellets and briquettes. The generated 'producer gas' is cleaned using bio-filters and used in specially designed gas engines for electricity generation. The Central Institute of Agricultural Engineering (CIAE), Bhopal, has developed a power plant running on 'producer gas' generated from biomass.

### *Biochar production*

Biochar is a high carbon material produced through slow pyrolysis (heating in the absence of oxygen) of biomass (Fig. 6). It is a fine-grained charcoal and can potentially play a major role in the long-term storage of carbon in soil, i.e., C sequestration and GHG mitigation. However, with the current level of technology, it is not economically viable and



*Fig. 6. Low-cost pyrolysis kiln for preparation of biochar  
(Courtesy: T.J. Purakayastha, IARI, New Delhi)*

cannot be popularized among the farmers. However, once all the valuable products and co-products such as heat energy, gas like  $H_2$  and bio-oil are captured and used in the biochar generation process, it would become economically-viable. There is a need to develop low cost pyrolysis kiln for the generation of biochar to utilize surplus crop residues, which are otherwise burnt on-farm.

## **Crop residues management strategies in different countries**

As discussed earlier, there are several technologies in India for managing crop residues. However, there are a few constraints, which limit the large-scale adoption of these technologies. One major handicap in using large amounts of straw is the high cost and labour requirement for its collection and transportation. Some countries have developed strategies for successful management of crop residues to avoid on-farm burning. In China, where about 700 Mt crop residues are generated annually, 31% of crop residues are left in the field, 31% are used for animal feed, 19% are used for bioenergy generation and 15% are used as fertilizer (Jiang et al., 2012).

In USA on farm burning has been regulated in some of the states. For example, in California farmers require a permit for crop residues burning, which can be carried out only on 'burn-days' determined by the local authorities in consultation with the California Air Resource Board. The crop residues are also required to be shredded and piled where possible. The crop residues are used as a source of energy in some countries like Indonesia, Nepal, Thailand, Malaysia, Philippines, Indonesia and Nigeria; for composting in Philippines, Israel and China; as animal feed in Lebanon, Pakistan, Syria, Iraq, Israel, Tanzania, China and countries in Africa; for mushroom cultivation in Vietnam and even burnt on-farm in China, USA, Philippines and Indonesia.

## **Managing crop residues with conservation agriculture**

Indian agriculture has made significant progress in the last five decades. However, for past some years it is facing various challenges with stagnating net sown area, reduction in per capita land availability, climate change effect and deterioration of land quality. The root cause of degradation of agricultural land is its low soil-carbon content that disrupts many important soil-mediated ecosystem functions. Conservation agriculture, with the following three core inter-linked principles, is a viable option for sustainable agriculture and is an effective solution to check land degradation (Kassam, 2011).

- Minimizing mechanical soil disturbance and seeding directly into untilled soil to improve soil organic matter content and soil health.
- Enhancing organic matter cover on soil using cover crops and/or crop residues. This protects the soil surface, conserves water and nutrients, promotes soil biological activity and contributes to integrated pest management.
- Diversification of crops in associations, sequences and rotations to enhance system resilience.

These principles can be integrated into most of the rainfed and irrigated production systems, including horticulture, agroforestry, organic farming, rotational farming and integrated crop-livestock systems to strengthen ecological sustainability. Worldwide about 105 Mha land is under conservation agriculture and it is increasing with time (Fig. 7). However, USA, Brazil, Argentina, Canada and Australia occupy about 90% of the area under conservation agriculture in the world. The conservation agriculture, which is advocated as alternative to the conventional production system, has been adopted by the Food and Agriculture Organization (FAO) of the United Nations as a lead model for improving productivity and sustainability.

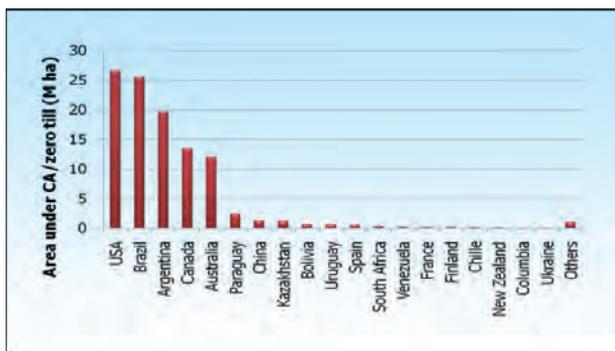


Fig. 7. Area under conservation agriculture in the world  
(Source: Derpsch and Friedrich, 2010)

Recent estimates have revealed that conservation agriculture-based resource conserving technologies (RCTs) that include laser assisted precision land levelling, zero/reduced tillage, direct drilling of seeds, direct seeding of rice, unpuddled mechanical transplantation of rice, raised bed planting and crop diversification are being practised over 3 Mha in South Asia. The RCTs with innovations in residue management avoid straw burning, improve soil organic C, enhance input efficiency and have the potential to reduce GHGs emissions (Pathak et al. 2011).

Permanent crop cover with recycling of crop residues is a pre-requisite and integral part of conservation agriculture. However, sowing of a crop in the presence of residues of preceding crop is a problem. But new variants of zero-till seed-cum-fertilizer drill/planters such as Happy Seeder (Fig. 8), Turbo Seeder and rotary-disc drill have been developed for direct drilling of seeds even in the presence of surface residues (loose and anchored up to 10 t ha<sup>-1</sup>). These machines are very useful for managing crop residues for conserving moisture and nutrients as well as controlling weeds in addition to moderating soil temperature.



*Fig. 8. A 'Happy Seeder' for direct drilling of seeds in the presence of surface residues (Courtesy: CSISA, CIMMYT-IRRI, New Delhi)*

In the areas, eastern India for example, where crop residues have competing uses as animal feed, roof thatching and



*Fig. 9. Leaving of varying lengths of stubbles for enriching soil organic C content (Courtesy: B. Mandal, BCKV, West Bengal)*

domestic fuel, at least some parts of the stubble should be left in the fields to contribute to soil organic C. This technology has been successfully applied in several experiments at Bidhan Chandra Krishi Viswavidyalaya (BCKV), West Bengal (Fig. 9).

Due to less biomass productivity and competing uses of crop residues, the scope of using crop residues for conservation agriculture is limited in dryland ecosystems. Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, has shown that in dryland ecosystems, where only a single crop is grown in a year, it is possible to raise a second crop with residual soil moisture by covering soil with crop residues (Fig. 10).



*Fig. 10. Growing of horse gram during post-rainy season with maize residues under conservation agriculture in rainfed condition (Courtesy: Ch. Srinivas Rao, CRIDA, Hyderabad)*

### ***Impact of crop residues on soil health and crop yield***

Incorporation of crop residues into soil or retention on the surface has several positive influences on physical, chemical and biological properties of soil. These practices increase hydraulic conductivity and reduce bulk density of soil by modifying soil structure and aggregate stability. Mulching with plant residues raises the minimum soil temperature in winter due to reduction in upward heat flux from soil and decreases

soil temperature during summer due to shading effect. Retention of crop residues on the soil surface slows the runoff by acting as tiny dams, reduces surface crust formation and enhances infiltration. The channels (macro pores) created by earthworms and old plant roots, when left intact with no-till, improve infiltration to help reduce or eliminate runoff. Reduced evaporation from the upper strata of soil coupled with improved soil characteristics essentially leads to higher crop yield in many cropping and climatic situations.

The crop residues act as a reservoir for plant nutrients, prevent leaching of nutrients, increase cation exchange capacity (CEC), provide congenial environment for biological N<sub>2</sub> fixation, increase microbial biomass and enhance activities of enzymes such as dehydrogenase and alkaline phosphatase. Increased microbial biomass can enhance nutrient availability in soil as well as act as sink and source of plant nutrients. Leaving substantial amounts of crop residues evenly distributed over the soil surface reduces wind and water erosions, increases water infiltration and moisture retention, and reduces surface sediment and water runoff.

The crop residues play an important role in amelioration of soil acidity through the release of hydroxyls especially during the decomposition of residues with higher C:N, and soil alkalinity through application of residues from lower C:N crops, including legumes, oilseeds and pulses. The role of crop residues on carbon sequestration in soils would be an added advantage in relation to climate change and GHGs mitigation.

Establishment and maintenance of soil health is inextricably linked to the achievement of effective and efficient nutrient management goal in conservation agriculture. The conservation agriculture builds a stratified layer of crop nutrients, especially P on or near the soil surface. While reduced tillage and soil organic C build-up contribute to stable soil structure, this undisturbed structure produces macro pores

and preferential flow channels that can direct nutrients, including P, downward into deeper parts of the soil profile. The choice of cropping systems can have a strong influence on the soil quality through processes such as nutrient depletion and/or enrichment through production of biomass/crop residues, need for external inputs and impact on environment. Conservation tillage can reduce overall nitrogen loss by reducing ammonium-nitrogen loss and organic-nitrogen loss with sediment; however, it may not reduce nitrogen leaching in the nitrate form.

Yield response with residues management varies with soil characteristics, climate, cropping patterns, and level of management skills. Higher yields with crop residues application result from increased infiltration and improved soil properties, increased soil organic matter and earthworm activity and improved soil structure after a period of 4-7 years.

### *Impact of crop residues on pests*

Incorporation of crop residues in conservation agriculture has direct and indirect effects on pests. For example, crop residues directly affect egg laying of beetles and cutworms. Lower soil temperature and higher soil moisture content under crop residues would also affect pest infestation. Indirectly, residues change the type and density of weeds, which in turn influence insects and natural enemies. Crop residues generally increase diversity of useful arthropods and help in reducing pest pressure. The surface residues may ensure survival of a number of insects, both harmful and beneficial. Reduced tillage systems particularly under staggered planting system of crops in monoculture, may contain higher levels of pest inoculums than the conventional system. Further, the decomposition of crop residues along with several inter-related factors like climate, crop geometry, irrigation and fertilization, cultural practices and pesticides may affect the survival of insects in crop residues. The decomposition of residues brings out a chemical change in soil which may affect the host reaction to

pests. The decomposition of plant residues may produce phytotoxic substances, particularly during early stages of decomposition. The effects could be severe in reduced tillage systems which incorporate huge amount of crop residues into the soil and an extra application of N is made to hasten decomposition of these residues. A change in weed ecology is expected to influence the survival of several of those insects which tend to develop on weeds, particularly during the fallow period. Since the zero/reduced tillage system reduces the fallow period among crops, it may result in altered incidence of certain insects.

Population of termite and white grubs generally increases under the reduced tillage. However, the effect of crop residues on termite damage is contentious. Under sufficient crop residues, white grubs do not damage the crop even at a very high density. However, at some of the sites, organic mulching has been reported to increase damage of cutworms due to moisture conservation. Also crop residues on the soil surface that conserves the moisture, may favour snails and slugs, causing damage to crops. Increased pest and weed problems during the 'transition period' are major hurdles in adoption of conservation agriculture by farmers. Non-judicious application of pesticides under such situations may disrupt the ecosystem and cause pest outbreaks. Therefore, integrated pest management (IPM) should be adopted as a necessary component of a conservation agriculture system.

### *Constraints of using crop residues with conservation agriculture*

A series of challenges exist in using crop residues in conservation agriculture. These include difficulties in sowing and application of fertilizer and pesticides, and problems of pest infestation. The conservation agriculture with higher levels of crop residues, usually requires more attention on timings and placement of nutrients, pesticides and irrigation. Lot of improvements have been done in the zero-till seed-cum-

fertilizer drill system to give farmers a hassle-free technology. Weed control is the other bottle-neck, especially in the rice-wheat system. Excessive use of chemical herbicides may not be a desirable option for a healthy environment. Nutrient management may become complex because of higher residues levels and reduced options for application of nutrients, particularly through manure. Application of fertilizers, especially N entirely as basal dose at the time of seeding may result in a loss in its efficiency and environmental pollution. Sometimes, increased application of specific nutrients may be necessary and specialized equipments are required for proper fertilizer placement, which contributes to higher costs. Similarly, increased use of herbicides may become necessary for adopting conservation agriculture. Countries that use relatively higher amounts of herbicides are already facing such problems of pollution and environmental hazards.

Further limiting factor in adoption of residues incorporation systems in conservation agriculture by farmers include additional management skills, apprehension of lower crop yields and/or economic returns, negative attitudes or perceptions, and institutional constraints. In addition, farmers have strong preferences for clean and good looking tilled-fields vis-a-vis untilled shabby looking fields.

## **Research needs for efficient crop residues management with conservation agriculture**

Management of crop residues with conservation agriculture is vital for long-term sustainability of Indian agriculture. Hence, burning of residues must be discouraged and utilized gainfully for conservation agriculture in improving soil health and reducing environmental pollution. Regions where crop residues are used for animal feed and other useful purposes, some amount of residues should be recycled into the soil. Several technologies are available for efficient use of crop residues in conservation agriculture. However, they require substantial improvement for large scale adoption by resource

poor and low-skilled farmers. For example, Happy Seeder seems to be one of the potential technologies for managing crop residues. To facilitate adoption of Happy Seeder, farmers need clear guidelines for optimum irrigation, fertilizer management, pest management and long-term effects on soil health. Efforts are required to quantify the economic, social and environmental benefits of conservation agriculture-based practices under different situations. These can then form a basis for policy level issues in relation to C sequestration, erosion control, fertilizer-use efficiency and incentives to retain crop residues. Some of the research areas which need immediate attention are discussed below.

### *Generation and utilization of crop residues*

- Development of region-specific crop residues inventories including total production from different crops, their quality, utilization and amount burnt on-farm, for evolving management strategies. Satellite imageries should be used to estimate the amount of residues burnt on-farm.
- Assessing the quality of various crop residues and their suitability for off-farm (e.g. animal feed, composting, energy, biogas, biochar and biofuel production) and on-farm (e.g. conservation agriculture) purposes.

### *Basic and strategic research*

- Developing crop varieties to produce more root biomass to improve the natural soil resource base.
- Developing simulation models for prediction of impact of conservation agriculture on crop growth, soil properties, crop yield and farm income.
- Enhancing decomposition rate of residues for *in-situ* incorporation.
- Designing new generation of long-term experiments to study the impact of conservation agriculture on soil

health, water and nutrient use efficiency, C sequestration, GHGs emission and ecosystem services.

- Assessing life-cycle of residue-based conservation agriculture vis-à-vis conventional method of disposing crop residues by burning and other competing uses.

### *Optimizing competing uses of crop residues*

- Analysing the benefit:cost, socio-economic impact and technical feasibility of off and on-farm uses of crop residues.
- Optimizing residues use that can be retained for conservation agriculture without affecting the crop-livestock system, particularly for the regions where residues are the main source of fodder.
- Assessing the suitability of residue retention/incorporation in different soil and climatic situations.
- Quantifying the permissible amount of residues of different crops which can be incorporated/retained, depending on the cropping systems, soil characteristics, and climate without creating operational problems for the next crop or chemical and biological imbalance.
- Assessing benefit:cost and environmental impact of residue retention/incorporation in conservation agriculture vis-à-vis residue burning for short and long-term time scales.

### *Water and nutrient management with conservation agriculture*

- Developing complete package of practices for conservation agriculture for prominent cropping systems in each agro-ecological region, particularly in rainfed and dryland eco-systems.
- Scheduling irrigation in conservation agriculture fields (i) with anchored residues, (ii) with surface carpet of residues and (iii) no residues.

- Developing soil test method, fertilizer recommendations and customized fertilizer application for conservation agriculture taking into account nutrient requirement of the cropping system.
- Assessing the role of legume residues in sustaining/maintaining C:N:P:S in the soil.

### *Pest management in conservation agriculture*

- Developing package of practices for integrated pest management (IPM) involving crops, tillage, residues, modified planting methods and pesticides in conservation agriculture to reduce use of pesticides and to minimize cost of production and environmental pollution.
- Evaluating weed dynamics (i.e., shift and virulence in weed flora, biology), their interference potential and suitable management practices with low-cost, environment-friendly herbicides in crop residue-based conservation agriculture.
- Developing technologies for termite control in order to enhance yield and the value of residues left on surface during long interval period between two crops.

### *Machinery for conservation agriculture*

- Development of appropriate farm machinery to facilitate collection, volume reduction, transportation and application of crop residues, and sowing of the succeeding crop under a layer of residues on soil surface.
- Modifying combine harvester to collect and remove crop residues from field. Twin cutter bar type combine harvester for harvesting of top portion of crop for grain recovery and a lower cutter bar for straw harvesting at a suitable height and windrowing should be developed for proper management of straw.

## Policy and development needs for efficient crop residues management with conservation agriculture

The way crop residues are used and managed by millions of farmers depends on their individual perceptions about the benefits, largely economic, both short- and long-term and the opportunities available. The current policy instruments, if any, draw from the need to control air pollution resulting from the negative impacts of burning of crop residues and not from the benefits of conservation agriculture in achieving goals of sustainable agriculture. The benefits of conservation agriculture relate to soil health improvement, biodiversity enhancement, C sequestration, reduced GHGs emissions and improved use-efficiency of inputs. There is a need to undertake policy-related research to quantify the benefits under a range of situations to aid policy level decisions. In the past, role of crop residues has been viewed and evaluated largely in terms of nutrients balance ignoring the multi-functionality of soils in terms of maintaining biodiversity, GHGs mitigation, improved input-use efficiency, sustaining agriculture and human health. These are the new dimensions of the problems which Indian agriculture is currently facing and need to be addressed.

### *Laws and legislation*

- Developing a crop residues management policy for each state defining clearly various competing uses.
- Developing and implementing appropriate legislation on prevention and monitoring of on-farm crop residues burnings through incentives and punishment.
- Supplying machineries for conservation agriculture on subsidized rates, promoting custom hiring systems and providing soft loans for purchase of implements.
- Introducing C-credit schemes to benefit the farmers who follow conservation agriculture for carbon sequestration and GHGs mitigation.

- Classifying crop residues as amendments (like lime or gypsum) and their use in agriculture should attract subsidy like any other mineral fertilizer or amendment.

### *Capacity building and awareness generation*

- Capacity building of under- and post-graduate students and training of farmers. Every agricultural university should have courses on crop residue management and conservation agriculture both at under- and post-graduate levels.
- Establishing self-help groups and encouraging unemployed youths to take up custom hiring of conservation agriculture machineries as a profession.
- Including the component of conservation agriculture in soil health card for proper monitoring of crop residues retention/burning and its impact on soil health.
- Familiarizing conservation agriculture technologies at KVKs and state agricultural departments for awareness generation among the farmers.
- Intensive collaborative research in conservation agriculture with reference to pest and their natural enemies in different cropping systems.

### *Development activities*

- Each university, research institute and NGO committed to sustainable development of agriculture should start working with some selected farmers. Their experience should be used for improving the conservation agriculture technology and overcoming the constraints to make conservation agriculture a success.
- The emphasis should also be laid on recycling of other organic wastes along with crop residues. As the availability of such organic resources is site-specific, an inventory of the potentially available organic wastes should be developed for their use in the target regions in a systematic way.

## Model for management of crop residues

As the generation, demand, quality, feasibility and economics of crop residues management vary from region to region, a region-specific and need-based crop residues management plan should be laid. While developing the plan, the following points need to be considered.

- Quantity of crop residues generated in the region
- Seasonal availability of crop residues
- Priority of competing uses of residues
- Availability of technologies and its short- and long-term impacts
- Availability of infrastructure and equipment for management of crop residues

A model plan given in Table 2 may be used as a guideline for managing crop residues at local and regional scales.

**Table 2. Model plan for managing crop residues at local and regional scales**

Query	Response	Crop residues management options
1. Can crop residues be used for conservation agriculture? If the answer is No, move to query 2	Yes	<ul style="list-style-type: none"> <li>● Retain it on soil surface</li> <li>● Use drill for sowing with residues (e.g. Happy Seeder)</li> <li>● Follow conservation agriculture for all crops in rotation</li> </ul>
2. Can it be used as fodder? If the answer is No, move to query 3	Yes	<ul style="list-style-type: none"> <li>● Leave stubbles in field</li> <li>● Enrich fodder with supplements (e.g. urea and molasses)</li> <li>● Use manure in conservation agriculture</li> </ul>
3. Can it be used for biogas generation? If the answer is No, move to query 4	Yes	<ul style="list-style-type: none"> <li>● Leave stubbles in field</li> <li>● Adopt community biogas plant (e.g. KVIC design modified by IARI)</li> <li>● Use slurry in conservation agriculture</li> </ul>

Query	Response	Crop residues management options
4. Can it be used for composting?  If the answer is No, move to query 5	Yes	<ul style="list-style-type: none"> <li>• Leave stubbles in field</li> <li>• Adopt modern composting technique (e.g. IARI model)</li> <li>• Use compost in conservation agriculture</li> </ul>
5. Can it be used for bio-fuel generation?  If the answer is No, move to query 6	Yes	<ul style="list-style-type: none"> <li>• Leave stubbles in field</li> <li>• Install bio-fuel plant</li> <li>• Use liquid slurry in conservation agriculture</li> </ul>
6. Can it be used for electricity generation?  If the answer is No, move to query 7	Yes	<ul style="list-style-type: none"> <li>• Leave stubbles in field</li> <li>• Install biomass-energy plant (e.g. KPTL model)</li> <li>• Use ash in conservation agriculture</li> </ul>
7. Can it be used for gasification?  If the answer is No, move to query 8	Yes	<ul style="list-style-type: none"> <li>• Leave stubbles in field</li> <li>• Install biomass gasifier (e.g. CIAE model)</li> <li>• Use ash in conservation agriculture</li> </ul>
8. Can it be used for biochar making?	Yes	<ul style="list-style-type: none"> <li>• Leave stubbles in field</li> <li>• Install biochar klin (e.g. IARI model)</li> <li>• Use biochar in conservation agriculture</li> </ul>

## Conclusions

India has the challenging task of ensuring food security for the ‘most’ populous country by 2050 with one of the largest malnourished population. Besides, farming in future has to be multi-functional and ecologically sustainable so that it can deliver ecosystem goods and services as well as livelihoods to producers and society. Hence farming should effectively address local, national and international challenges of food, water and energy insecurity; issues related to climate change; and degradation of natural resources. For ensuring the country’s food security both in the short- and long-term perspectives and making agriculture sustainable, the soil

resource base must be strong and healthy. Conservation agriculture, with crop residues as an integral component, is an effective solution to the aforesaid challenges and ensures a strong natural resource base.

The conservation agriculture sets principles towards sustainable production systems and these principles need to be translated into practices as per site-specific requirements. The best way to go about is to start working with a group of selected farmers from varying situations, use their knowledge and experiences and assess what and how much can be achieved and what is needed more to make conservation agriculture a success.

Crop residues are of great economic values as livestock feed, fuel and industrial raw material, and in conservation agriculture for which it is a pre-requisite. Crop residues, either partly or entirely must be used for conservation agriculture for ensuring the country's food security, making agriculture sustainable and the soil resource base healthy. All stakeholders viz, farmers, supply and value chain service providers, researchers, extension agents, policymakers, civil servants and consumers need to be engaged in understanding and harnessing the full potential of these valuable resources for sustainability and resilience of Indian agriculture. We believe that the research, policy and development programmes as outlined in this bulletin will serve a great deal in managing crop residues at local and regional scales.

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