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Residue Management and Nutrient Dynamics in Conservation Agriculture: A Review

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ABSTRACT

Conservation tillage significantly influence the physico-chemical properties of soil that makes microclimate conducive for crop growth and productivity. The use of chemical fertilizers alone to sustain high crop yield has not been successful due to its effects on soil acidity, nutrient leaching, degradation of soil's physical properties and organic matter. Higher levels of soil organic carbon, microbial biomass of carbon and nitrogen, nitrogen mineralization, total nitrogen and extractable phosphorus are directly related to crop residues under conservation tillage management. Conservation agriculture (minimum or no tillage with residue retention and crop rotation) practices has potential for increasing the nutrient supply to crops through changes in the mineralization and immobilization of nutrients by microbial biomass and provide an eco-protective environment for sustainable production. Conservation agriculture reduces nutrient percolation/leaching from the soil profile, can redistribute the soil profiles thus affects nutrient supply, and its storage. Entire soil-plant continuum changes after the conversion from conventional agriculture to conservation agriculture. The review therefore highlights the nutrient dynamics under crop residue management with no or minimum tillage.

Keywords: conservation tillage, residue retention, mineralization, nutrient, dynamics

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INTRODUCTION

Conservation Agriculture (CA) seems promising to improve nutrient availability and soil fertility (Vanlauwe et al 2006). CA system has the three pillars of no tillage, crop residue and crop rotation have significant influence on soil nutrient dynamics (Majumdar et al 2018). CA not only utilizes crop residues at the same time recycles plant nutrients in soil, improves soil properties and provides environmental benefits. Avoiding in-situ burning also manages residues in productive and profitable manner. Asian countries share, respectively, ~43% and 90% of wheat and rice residues produced globally. Nepal produces 22 million ton of crop residues each year. Rice wheat maize contribute 3/4th of residue, largest from rice (47%) followed by maize (25%) (Jawed 2020). In Nepal, crop residue is served as major feed for animals and left over residue is burnt in field. About 300N kg ha-1, 300K kg ha^{-1} and 30 kg ha^{-1} P is lost from rice-wheat sequence field with yield of 7 tons/ha rice and 4 tons/ha wheat (Singh 2003). Moreover, 40-80% of N is lost in form of ammonia when wheat residue is burnt (Samra et al 2003). Particulate emissions from residue burning have been considered as the potential cause of Asian Brown Cloud formation over Asian regions (Ramanathan and Carmichael 2008) also estimated as the 4th largest type of biomass burning (Andreae and Merlet 2001). Crop residue retention rather than its burning has been considered as best strategy for managing residue in-situ and to mitigate climate change (Badarinath et al 2009). Depending on crop type, residue contains substantial amount of nutrients and its improper management leads to loss of soil nutrients, biological diversity and release of various pollutants. Nutrient management has been identified as the "fourth pillar" of CA (Vanlauwe et al 2014). An understanding of how nutrients move and react in soil is necessary for proper fertilizer management in reduced tillage systems whilst the sub-optimal implementation of other crop management practices do not lead to failure of CA. Loss of 10% of initial soil organic matter (SOM) content with plow tillage had been reported by Rhoton (2000). Crop rotations with leguminous crops have potential to increase soil nitrogen (N) concentration through biological nitrogen fixation. About one-third of global greenhouse gas emission is attributed to changes in tillage scenarios (Gattinger et al 2014). Poper management and utilization of crop residues can be important factor in achieving the increased food production and enhanced soil fertility. Present study aims to review the information on nutrient dynamics under CA.

Crop residues as a source of plant nutrients

Residue adds significant amount of macro and micro nutrients to soil. At maturity stage, rice straw retains about 40% N, 30–35% P, 80–85% K and 40–50% S (Dobermann and Fairhurst 2000), wheat straw retains about 25–30% N and P, 70–75% K and 35–40%(Singh and Sidhu 2014). One ton of rice and wheat residues contain about 9–11 kg S, 777 g Fe, 745 g Mn and 100 g Zn. Rice residue decomposition using litter bags released ~6 kg N ha^{-1} (15% of initial) and 12 kg N ha^{-1} (27% of initial) in sandy-loam and silt-loam soils, respectively. Based on N ratio in urea, one ton of straw has 8 kg N, which replace around 28 kg of urea as fertilizer (Yadvinder-Singh et al 2010).

Table 1. Quality composition of crop residues determining its decomposition and nutrient release

Crop residues	%C	%N	C: N	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	References
Maize stover	47.0	0.62	76	43.2	19.3	22.5	Zhang et al (2015)
Wheat straw	44.70	0.48	93	33.0-40.0	20.0-25.0	15.0-20.0	Mckendry (2002)
Rice straw	37.8	0.48	79	40.0	18.0	5.5	Prasad et al (2007)

In-situ residue management options in CA

Retention of crop residue

Providing at least 30% soil cover (Verhulst et al 2010), combined with reduced tillage (RT) soil organ mater (SOM). Sah et al (2014) zero-tillage (ZT) in combination with crop residues preservation in soil increased rice-wheat system production with positive nutrient balance and increased usable P_2O_5 (5.8%), exchangeable K_2O (7.8%), and soil OM (1.5%). Chen et al (2019) revealed residue from burning to field retention might save about 149.9 Tg yr^{-1} of CO_2 emission while sequestering 24.4 Tg C yr^{-1} of soil organic carbon (SOC). Use of rice, maize straw as mulch raises C: N ratio, alter balance of nitrogen mineralization and immobilization or leads to prolonged N immobilization by microbes rendering N unavailable for crop growth in short term. When compared to burning, leaving residues on surface increased soil NO_3 concentration by 46%, N uptake by 29%, and yield by 37%. Keeping 100% residue cover is good, but need at least 90% to reduce evaporation from soil surface Mandal et al (2004).

Crop residue incorporation

Tripathi et al (2010) incorporation of residue along with no-till (NT) increased wheat yield to 2.83 t ha^{-1} from 2.05 t ha^{-1} with conventional tillage (CNT). Uptake of about 25%, 50% and 75% of N and P, K, S are retained by cereal when residues are incorporated than through green manure (Singh, 2003). Wheat yields reduced for first one to three years after rice straw incorporation 30 days before wheat planting but straw incorporation had no effect on wheat yields in subsequent years. In residues incorporated under CNT systems, microbial activity is enhanced and more carbon (C) is mineralized and lost as CO_2. Incorporation recycles nutrients, cause temporary immobilization of nutrients, necessitating use of additional nitrogenous fertilizer to rectify high C:N ratio. Residue should be incorporated 7 to 30 days before planting, requires bulk quantities and is costly.

Table 2: Effect of crop residue in a rice-wheat rotation and soil physiochemical properties over a 7-year periods.

Residues	pH	EC (dSm^{-1})	O.C%	Avail.N (kg ha^{-1})	Avail.P(kg ha^{-1})	Avail.K (kg ha^{-1})
Incorporated	7.7	0.18	0.75	154	45	85
Removed	7.6	0.13	0.59	139	38	56
Burned	7.6	0.13	0.69	143	32	77

Source: Mandal et al., 2004

Mulching

Straw mulching increased yield by 18.3 % and fertilizer use efficiency by 17.6 % (Peng et al 2015). Moisture, SOM, yield attributes of maize were maximum when mulch applied @12 t ha^{-1}, while maximum grain yield was obtained at @ 8 t ha^{-1}. Surface residues increased soil NO_3 concentration by 46%, N uptake by 29%, and yield by 37% (Cook et al., 2006). Baudron et al.,(2015) mulching improved soil quality of topsoil twice the plots with to no residue retention. Low or delayed germination observed with high quantities of residues under cool, humid climate. At dry semi-arid sites evapotranspiration is comparable to precipitation so mulch increase yield. Residue with high C/N ratio (cereals) improve soil acidity by release of hydroxyls and with low C/N ratio (oilseeds, pulses) mitigate alkalinity. Decomposition of residues may produce phytotoxic substances during early stage of decomposition.

On farm residue burning

Burning of residues leads to release of soot particles, leads to emission of greenhouse gases, causing global warming, increases short term availability of nutrients like P and K reduces soil acidity leads to loss of SOM and nutrients like N and S. After burning, temperature of 7 cm topsoil increases such that C-N balance in soil changes rapidly Increase temperature causes death of bacterial, fungal species. Burning increases the exchangeable $NH4^{+}$ and bicarbonate-extractable P content, but there is no buildup of nutrients. About 70%, 7% and 0.7% of C present in rice straw is emitted as CO_2, carbon monoxide and methane, respectively, while 2% of N in straw is emitted as nitrous oxide upon burning (Gadi 2003). One ton of rice straw burning results in loss of 5.5 kg N, 2.3 kg P, 25 kg K, and 1.2 kg S. Burning removes around 80– 90% N, 25% P, 20% K, and 50% S contained in agricultural residues in form of gaseous and particulate materials (Sangeet and Kumar 2016).

Environmental impact

No and minimum-tillage resulted in 56 % and 40 % reduction in CO_2 equivalent emissions respectively compared to ploughing. Shifting from CNT to ZT reported to yield C sequestration rate of 367-3667 kg CO_2 ha^{-1} $year^{-1}$ as oxidation of CO_2 into atmosphere is reduced. CNT decreases exposure of un-mineralized organic substances to microbial processes, reducing organic matter decomposition and CO_2 emission. CNT produced significantly higher N_2O emissions than ZT (Kessavalou et al 1998). Conservative tillage (CT) is more energy efficient than CNT, as fewer machinery operations require less fossil fuel thus CO_2 emission reduced. Meta-analysis on residue retention and N_2O emissions by Shan and Yan (2013) indicated that sole crop residue incorporation increases in N_2O emission but combine application of residue with mineral fertilizers reduce N_2O emissions. N_2O emission is negatively correlated with residue C/N ratio.

Nutrient availability at different crop growth stages in CA

At sowing, higher available N under CA was due to retention ($\sim$14 t ha^{-1} yr^{-1}) of residues at surface soil which upon decomposition supplied N Jat et al (2017). Lowest available N at panicle initiation and harvest stage was due to higher crop uptake from higher mineralization of SOM (Mehta et al 1963). Availability of N in soil depends on transformation of organic and inorganic forms of N in soil upon application of humic acid and organic matters. Higher quantity of available P and K at sowing was due to higher amount of residues retained at soil surface which supplies P and K upon mineralization. With progress to crop growth stages, P concentration decreased due to crop uptake which might be due to higher C mineralization in different growth stages (Singh and Singh 1993). In residue retained plot N-mineralization was lower than in residue removed at seedling stage. At grain-forming stage N mineralization in residue retained exceeded over residue removed. Higher microbial biomass at harvest of wheat was due to higher mineralization of residues at maturity which provide higher amount of organic matter for microbial growth. At tillering stage of rice both C and N declined due to rapid growth of aerial parts and expansion of roots that caused more absorbance of nutrient from soil and created competition with soil microbes (Zeng et al 2005).

Root mass, its distribution and nutrient uptake in CA

Residue retention resulted in better equilibrium between macro and micro-porosity leading to increased root biomass in surface soil layer thus, able to take up sufficient nutrients. Maize root system developed in surface layers under NT contributes root lodging resistance. Effect of NT on roots development was evident on maize, soybean, wheat in top soil layer (0–5 cm), where it increased RLD (Root Length Density), RDW (Root Dry weight) compared to CNT (Bottinelli et al 2017*)*,opposite in 10–50 cm, and no differences below 50 cm. NT significantly reduced root C:N ratio of maize, increased in soybean and did not affect C:N ratio of wheat because NT on coarse roots, decreased average roots N content. RLD at flowering was higher in maize under NT than under CNT(Conventional tillage) in sandy and well-drained sites while in fine-textured soil roots were generally more abundant, finer and longer under CNT, because of higher root downward progression, than under NT (Li et al 2017a). Root N content was higher in NT than in CNT, which significantly lowered root C:N ratio under NT. Study on effects of nutrient and physical properties on root growth within a 0–30 cm profile found that root density below 7 cm was affected by soil compaction. Lupwayi et al. (2006) more bicarbonate extractable P in top 8 cm of soil with NT than CNT and 3.5 times greater available P in the 0–5 cm soil layer than in 5–15cm in NT. Long- term soybean-corn rotation showed root diameter distribution and root P content under NT (1313 mg kg^{-1}) was slightly higher than under MP (Moladboard Plough) (1106 mg kg^{-1}). ZT conserved, increased availability of nutrients, K, near soil surface where crop roots proliferate (Franzenluebbers and Hons 1996).

Ecological role of crop residue retention under conservation agriculture (CA) system

Residue retention and soil nutrient (SOM) pool

Combination of residue retention and mineral nutrient (especially N-based fertilizers) addition with RT improve affect SOC dynamics by improving above and below ground biomass, and resultant humic substances after below ground biomass degradation (Zhao et al 2013). Residue derived organic fertilizers complement mineral fertilizers by increasing fertilizer use efficiency, SOC storage, thus increase yield. In CA significant amount of SOC is stored up to 30 cm soil layer due to accumulation of organic C through high residue retention, crop rotation and less microbial degradation.

Improved soil microbiological properties

Quantity and diversity of residue, organic, inorganic amendment and tillage have substantial influence on SOM, exchangeable base cations, exchangeable Al content, pH, CEC, and soil C/N ratio, which affects soil bacterial genetic structure and activities (Lienhard et al 2013). Improved soil temperature and moisture optimally required by microbes provide better habitat for microbial activities thus modulates nutrient dynamics. Residue return increased microbial biomass and accumulation of C and N.

Risks associated with crop residue retention in conservation agriculture (CA) system

Degradation of in-situ retained residue leads to release of nutrients, pest infestations, GHGs emission, depending on residue composition. There is chance of crop failure or yield penalty in crop rotation. High quantity of residue availability on soil surface leads to high C/N ratio in no-tillage during initial phases of residue retention. Thus, may cause physiological reduction of available N resulting in poor performance of crop under no-till. In addition to competitive uses of residue as feedstock for livestock, bioenergy generation also considered as major constraints for CA. Residue burning is associated with large land holding farmers having modern agro-technological aids whereas residue utilization potential for small to medium land holding farmers is still higher. Therefore, for striking balance between residue retention and utilization, there is need to develop policies for wide group of stakeholders.

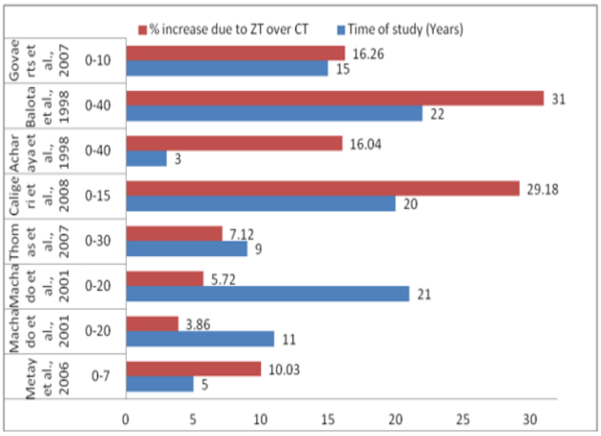
Nutrient stratification in no till (NT)

Less mobile nutrients like P and K have the potential to become stratified near the surface of the soil. Nutrients like nitrogen (N) and sulphur (S) are mobile in the soil, and tillage has little impact on their availability to plants. In long-term no-till studieslittle stratification occurred for N and S. Nutrients that end up in a chemical form that is mobile, like nitrate and sulfate are generally are less stratified (Harapiak 2009).

Soil Chemical properties

Soil organic matter(SOM), organic carbon(OC) and total carbon(TC)

ZT results in greater accumulation of SOM in surface layers (0–20 cm) than CT (Lal 1989). SOM is retained in C due to reduced oxygen availability below surface of NT(Doran, 1980). Permanent raised beds with full residue retention increased organic C by 1.37 times over conventional tilled raised beds with straw incorporation for 0–5 cm and by 1.16 times in 0–20 cm during the period of five years. Maximum SOC gain corresponded to 1.75 t C ha^{-1} $year^{-1}$ with 16 t ha^{-1} residues. Increased soil organic carbon (SOC) was significantly (+19.9%) higher in MT (minimum tillage) over CNT (6.46 g kg^{-1}) within two years. Plowing dispersed organic C from 0–20 cm soil depth down to 60– 80 cm in corn (Romkens et al 1999). Mineralization, immobilization and denitrification plays role in SOC level. C sequestration rate found to be 0.24, 0.46 and 0.62 Mg ha^{-1} yr^{-1} in sandy loam, loam and clay loam under ZT over CT .Ploughing accelerate mineralization of organic materials. N,C and accelerates oxidation by microbes but when tillage is reduced mineralization get slow and C remain high, organic C is humic in nature thus improve C sequestration. TOC content in CNT ranged from 22.41 to 23.99 g kg^{-1}, while of CT was 25.27 g kg^{-1} (Beare et al 1993).



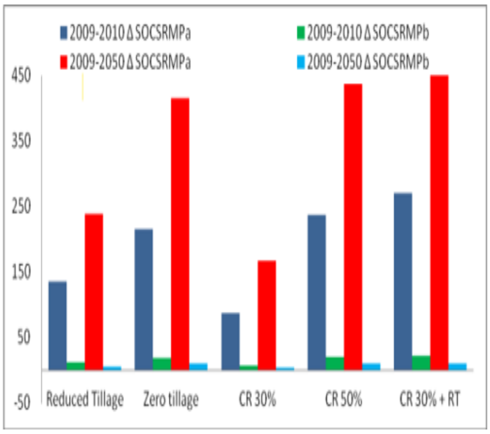


Fig 1: Percent increase in SOC due to adoption of ZT (Jat el al 2012) Fig 2 : Carbon sequestration potential (0-30cm) in (1980-2050) under recommended management practices (RMPs) using DNDC model a=C sequestration potential (Tg C), b=Average rate of C-sequestration (Tg Cyr-1) Chinese paddy soil (Xu et al 2011)

C:N, NH_4^+, NO_3^-

CNT increases soil C/N ratio in surface layer (0–5 cm) and decrease it in 5–20 cm depth over CT (Pugel 2007). Maximum increase (28% C, 33% N) was recorded in minimum tillage with residue (MT+Residu) retained over MT residue removed. As long as added C remains in soil, causes immobilization of applied N. Average soil NO_3^-–N content was 32.91 mg·kg^{-1} in CT while CNT recorded 14.65 mg·kg^{-1} representing 124.61% increase in NO_3^-N. CT recorded an average (NH_4^+)–N of 26.88%, higher than CNT(Govaerts et al 2006). With time, breakdown of SOM reaches a new equilibrium and potentially mineralizable N increases, resulting in more plant-available nitrate (NO3)-N and ammonium (NH4)-N. RT without straw stubble covering reduces leaching loss of nitrate-nitrogen, conducive to accumulation of $(NO_{3)}$-N. Legume residues (low C:N ratio) cause N mineralization but cereal residues with high C:N ratio can temporally immobilize N.

Total Nitrogen (TN), Total Phosphorus(TP), and Total Potassium(TK)

Reducing tillage from CNT to ZT in residue retained treatment increased nitrogen (N) by 29-104 % in in topsoil as NT improved topsoil OC and could fix soil N reduce losses through soil N leaching and volatilization (Chen et al 2009). Cropping intensity increased TN by 75.89% than WF (fallow cycles).TP was higher for NT at depths of 0–5 cm, it decreased more rapidly with increasing depth for NT than for CNT. TP ranged from 0.81 to 0.89 g·kg^{-1} CT, than CNT 0.68 g·kg^{-1}. P moves slowly in soil, easily fixed, and enriched in surface layer (Tian et al 2013). NT preserve mycorrhizal hyphae, produce stable soil structure, produces macro pores 20 and preferential flow channels that can direct nutrient, including P into deeper parts of soil. No-till have higher K in 0–0.025 m soil. Uptake of K by no-till corn was 130% of corn grown on plowed soils, but only in surface 2 inches of soil .K concentration was 1.65 times and 1.43 larger in 0–5 cm and 5–20 cm, respectively, compared to conventionally tilled raised bed (Moschler 1973).

Table 3. Impact of tillage system on distribution of available P in four successive soil depths

	Soil test available P (ppm)		
Depth	Plow and double disc	Chisel and disc	No till
0-2”	14.3	26.4	46.1
2-4”	12.4	12.2	14.2
4-6”	12.1	7.1	8.9
6-8”	11.3	5.7	6.6
Avg	12.5	12.8	19.1

Source (Blevins 1986)

Available Nitrogen(AN), Available Phosphorous(AP), and Available Potassium(AK)

NT significantly increased topsoil AN by 10% compared with CNT. Residue decomposition influences availability of N for crops through release of mineral N to soil. Low AN in surface can be attributed to immobilization of inorganic N (Locke and Hons,1988).Increased AP in upper 5 cm of NT. AP in CT ranged from 61.00 to 71.30 mg kg^{-1},while CNT attributed to chelation of inorganic P by accumulated soil OM (Noack et al 2014). Singh and Jones (1976) residues with P concentration of less than 0.22% resulted in net P immobilization. Organic compounds released during decomposition increase or decrease soil P adsorption capacity, depending on P content of residue. Reduced mixing of P in soils with high organic matter allow greater soluble P by occupying P-fixation sites and thereby increasing plant-AP in surface soil. Highest AK (257.645 kg ha^{-1}) recorded in plot kept with residue and least in where no retention of residue. Higher AK was found in no plot with maize + soybean–wheat (243.74 kg ha^{-1}) as a result of decarboxylation of organic anions on decomposition by microorganisms in undisturbed soil, buildup of SOM, under cover cropping enhanced K (+6.3%). Exchangeable K in 0-5cm was 1.35 times higher than 0-20cm and 1.75 times higher in 10-20cm. (Lupwayi et al 2006). AK available through residues is more pronounced temperate than tropical climate. Residues are rich in K.

Exchangeable Cation Exchange Capacity (CEC)

Exchangeable Ca^{2+}, Mg^{2+}, and Na^{+} affect acid-base balance. NT significantly increased topsoil Ca^{2+} and Mg^{2+} by 10% and 7% compared to CNT, respectively due to increased SOM (Jiang et al 2011).These ions are chemical drivers of aggregation, form cationic bridges with clay particles, OC, thus protecting OM from decomposition. CT had no significant influence on subsoil pH and CEC. Elevated SOM by cover crops contributed significantly to exchangeable Ca++ (+6.5%), Mg++ (+5.8%) as compared to no cover crop (NCC). Soil pH under CT was in range of 5.12 to 5.17, while that of CNT was 5.17, representing, 2.87% lower than CT. Lower pH in surface layer in CA is attributed to build up of SOM and release of organic acids upon decomposition while CNT increases soil pH. CT increase metal cation content thereby increasing amount of bases and balancing pH. Surface application of lime in NT is effective in raising soil pH at depths up to 30 cm (12 inches) or more (Caires 2006).

Electrical conductivity(EC)

Ghulam et al. 2014 reported that ZT with highest EC value and CNT with lowest EC values. Lower electrical conductivity under ZT compared with CNT pertains to the enhanced water movement in soil and improved soil aggregate development**.** The EC values in both soil depths were quite lower suggesting less chances of salt toxicity.

Available micronutrients

Zn, Mn, Fe,

Increasing supply of food crops with essential micronutrients result in significant increases in their concentrations in edible plant products. DTPA-extractable available Fe, Mn, Zn were significantly influenced by different CA practices in surface soil. At 0–15 cm soil depth, available Zn concentrations over 51% attributed to greater addition of Zn through crop residues and its accumulation in surface (Lopez-Fando and Pardo 2009). The concentration of all micronutrient cations decreased markedly with soil depth. Lower pH may have released previously nonavailable Mn and Fe from soil mineral. Fe concentration was above 50% in rice in CA due to greater availability of iron under reduced conditions in puddled transplanted rice which helps in conversion of less available $Fe3^{+}$ fractions to easily available $Fe2^{+}$(Ponnamperuma 1972).

Soil Biological properties

ZT improved total C by 45%, microbial biomass by 83% and MBC: total C ratio by 23% at upper 5 cm depth over CNT. Total organic C and available P showed significant correlation with microbial biomass C and microbial biomass P respectively while total N showed significant correlation with microbial N (Roldán et al 2003). Microbial biomass are used as indicator of potential C sequestration, ZT accumulated higher phosphatase activities in upper 0–5 cm depth than CNT (Mathew et al 2011). Tillage operations interrupts soil aggregates exposing organic matter to microbial degradation which oxidizes OM to CO_2. Maize-wheat-mungbean rotation with ZT along with residue retention resulted in 56% and 70% microbial biomass C and N respectively, 73% and 40% of phosphatise activity and β-glucosidaseactivity respectively and fungal diversity incomparison with rice-wheat system. CNT mineralized as much N as NT but had less toal soluble nitrogen (TSN) than NT. Population of denitrifying bacteria was almost half in tilled plot than ZT (Choudhary et al 2018).

Effect of CA practices on weed infestation

Weed density, weed dry biomass was significantly higher in wheat-rice cropping sequence in ZT than CNT (Singh et al 2015a). Proper selection of herbicide and application time reduced weed severity. In third year, rice and maize yield was higher than earlier years as residue attribute to increased soil fertility due to residual effects of previously applied fertilizers, low pest infestation, acted as mulch, which suppressed weeds. When mulch rates were less than 7 t dry matter ha^{-1}, weed emergence was stimulated compared to bare soil. Quantity of mulch needed to reduce weed emergence by 50% vary from 1 to 10 t dry matter ha^{-1}. Maximum effect, occurred with 4 t dry matter ha^{-1} or above (Buhler et al 1996). Response of weed to residue cover between temperate, tropical zones is affected by climate on dormancy release of weed populations. Efficiency of weed control also depends residue type and weed species. CNT weed seeds are deeply buried into soil and may not be able to germinate because of inadequate supply of moisture, nutrients. ZT suffer from significantly higher weed pressure because of surface placed seeds and better availability of water, nutrients, lesser herbicide efficacy and no soil inversion. Weeding time decreased as level of residue retention increased in maize. Residue cover influence weed emergence by altering light transmittance to soil surface through leaves of weed seedlings or allelopathic effects.

Impact of conservation agriculture (CA) on yield attributes and yield

Maize grain yield was significantly higher in no tillage (6.64 t ha^{-1}) and residue incorporated (7.02 tha^{-1}) than CNT (5.39 t ha^{-1}) and residue removed (5.02 t ha^{-1}) respectively. Residue retained had significantly longer seed fill duration than residue removed. Moisture conservation in NT and high organic matter in residue retained have caused longer seed fill duration thus increasing yield (Dawadi and Sah 2012). Yield of maize in it's 4th year under maize-rapeseed system NT produced grain yield of 5.21 as against CNT with 4.7 tha^{-1}. In same experiment, test weight was also recorded higher in NT with 263.9g as compared to 262.5g in CNT (Karki et al., 2014). In long-term experiments on rice-rice and rice-wheat cropping system in rice-rice cropping system ZT with residue retention increased effective tillers, no. of grains/spike and 1000 grain weight by 13.96-20.75, 41.67- 58.33 and 15.14-20.21%, respectively, over CNT in China (Liu et al 2003, 2005), mulched nonflooded rice yielded equal to or less than flooded rice with mulch, the wheat crop that followed the mulched rice yielded significantly higher than in plots receiving no mulch, resulting in higher system productivity and water savings. In maize, differences for ASI were found non-significant, however, ASI was smaller in crop residue incorporated which could be due to greater water, nutrient uptake, moisture conservation and reduced level of plant water stress. Increase in ASI is an indication of crop susceptibility to moisture deficit at flowering. When residue was removed, maize responded to N up to 160 kg ha^{-1} but when retained, kernel yield at 120 kg N ha^{-1} was statistically at par with 160 kg N ha^{-1}, suggesting a significant reduction in N requirement when residue was added.Yield parameters like shelling percentage and harvest index were enhanced with application of *Cajanus cajan* mulch @ 5 t ha^{-1} which is comparable to the NPK treated plot (Awopegba et al 2016). Maize protein yield recorded maximum with CT (ZT +permanent bed) under legume based maize rotation than CNT and highest values was with maize-chickpea-*Sesbania* cropping (Yadav et al 2017). Residue improve yields since productivity is a function of good nutrient retention and absorption under conducive environment, surface placement of residues under ZT tend to decrease N immobilization.Adoption of system of wheat intensification and ZT with residue retention significantly increased yield and yield parameter. Maize shoots grown in soil under ZT and surface banding also had higher P uptake at 35 days after emergence (DAE) and 70 DAE than other treatment (Canarache 2008).

Economy

Irrespective of residue management practices, DSR resulted in lower production costs and higher BCR than conventional transplanted rice in three years where net income and BCR were significantly higher under DSR + R. Higher cost of production in treatment without residue, in comparison with residue retention, was due to extra cost incurred in management of algae and weeds in former treatment.Tripathi (2010) at wheat growing field of Nepal suggested that incorporation of residue along with NT increased wheat yield to 2.83 t/ha from 2.05 t ha^{-1} led to an increase of profit from NR10,000 to more than NR 27,000 due to shift in CA system. In a rice–wheat rotation, skipping soil puddling in rice added USD 200 to net return ha^{-1} $year^{-1}$ over CNT based rice–wheat rotation, primarily because increased wheat yield, and retention of crop residue provided an additional net return of USD.146 ha^{-1} $year^{-1}$(Jat 2014). Prabhamani and Babalad (2017) concluded that surface retention of residues with no tillage and flat bed method resulted in net profit of Rs 60654 ha^{-1} over incorporated and CNT. Naab et al 2017 from analysis of partial budget by retention of residues in ZT of maize-soybean rotation found that cost of production for maize or soybean is 20-29% cheaper with highest returns and B:C ratio when compared to CNT. Hari Kumar et al (2018) concluded that retention of residues under NT gave 114% higher net returns (NRs 40200 ha^{-1}) under maize based cropping system at Nepal. Incorporation or mulching of residues improve performance of succeeding crops which is reflected in terms of growth and accumulation of drymatter. Significant response was observed in yield attributes and yield of succeeding crop due to increased fertility of soil and uptake of nutrients by crop when compared to residue removal plots. Incorporation or mulching of legume residues also resulted in higher net return and B:C ratio (Kihara et al 2012).

Nutrient dynamics and management in conservation agriculture(CA)

Mineralization-immobilization, sorption, desorption, dissolution-precipitation and oxidation-reduction (Majumdar et al 2018) govern source sink interactions characterizing nutrient dynamics. Nutrient management in CA can be addressed with 4R Nutrient Stewardship which involves the right source of plant nutrients, at the right rate, at the right time, and in the right place is core of balanced fertilization approach at broad acreage farms or in smallholder system. Principles Supporting Practices: The four “rights” provide simple checklist to assess whether given crop has been fertilized properly, they must work in synchrony with each other and with cropping system and management environment Site specific nutrient management (SSNM) enable farmers to adjust their fertilizer decision to optimally fill deficit between nutrient needs of crop and supply from indigenous sources such as soil, residue, organic inputs and irrigation in which fertilizer are recommended and yield target in such a way that mining of nutrients can be minimized (Majumdar et al 2015). Residue management Quantity composition placement of residues, influence decomposition rates. Progress of N mineralization and immobilization follows residue addition. If C:N ratio of residue is >20:1, net immobilization occur. Insufficient nitrogen in substrate induce organisms to draw mineral N in soil leading to immobilization of N. Residue C:N ratio decrease as decay proceeds because of decreasing C (respiration as CO_2) and increasing N (N immobilized from soil solution) and new equilibrium will be reached, accompanied by mineralization of N. Precision Agriculture (Berry et al 2003) uses component of utilizing all advanced tools of nutrient management together or as and when required for developing sustainable nutrient management protocol. Mitra et al (2019) Nutrient Expert® In North Eastern hill Nutrient Expert® with application of N, P_2O_5 and K_2O at 140, 32.9 and 65 kg ha^{-1} respectively in combination with zero tillage in wheat produced high yield, good economics and nutrient use efficiency over conventional practice. Crop rotation and introduction of legume or intercropping, appears important CA practice as they changes dynamics and release pattern of nutrients. Development of region-specific crop residues inventories, satellite imageries to estimate the amount of residues burnt, basic and strategic research to develop varieties to produce more root biomass to improve natural soil resource base, developing simulation models for prediction of impact of CA. Furthermore enhancing decomposition rate of residues for in-situ incorporation, design in long-term experiments to study impact of CA on soil health, water and nutrient use efficiency, C sequestration, GHGs emission, ecosystem, assessing life-cycle of residue based CA of disposing residues by other competing uses. Optimizing competing uses of residues through analyzing B:C ratio, socio-economic impact and technical feasibility. Optimizing residues without affecting crop livestock system. Assessing suitability of residue retention/ incorporation in different soil, climatic situations. Assessing environmental impact of residue retention/incorporation vis-à-vis residue burning for short and long-term. Developing package of practices for integrated pest management. Evaluating weed dynamics, their interference potential and suitable management with low-cost and is environment-friendly. Development of appropriate farm machinery e.g., modifying combine harvester to collect and remove residues. Twin cutter bar type combine harvester for harvesting of top portion of crop for grain recovery and lower cutter bar for straw harvesting at a suitable height and windrowing development.

CONCLUSIONS

Proper residue management help in climate change mitigation where global warming is the burning issue in today’s world. Use of chemical fertilizer is increasing at alarming rate which has resulted in economic loss and lack of use of organic sources as nutrient, their preservation is lacking but its destruction is aggravated, hence sustainability of agroecosystem is at risk. Pilot project demonstration site for residue management is needed. Government should provide incentives to the farmers for eco-friendly residue management strategies related to the ecological trade-offs. Future research need should focus on the small to medium land holding farmer's perspective for wider adaptation and success of this CA system. Upscaling CA through private and government sector is important as farmers are still unaware of CA practice.

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AUTHORS' CONTRIBUTION

S Kaduwal conceptualized the topic of the paper and prepared the manuscript jointly with the co-authors namely TB Karki, R Neupane, RK Bhattarai, B Chaulagain, P Ghimire, P Gyawaly, R Acharya, P Paneru, C Gyawali and SK Das.

CONFLICTS OF INTEREST

There is no conflict of interest regarding this manuscript.

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