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## **Integrated Soil, Water and Nutrient Management in Conservation Agriculture**

**Report of the FAO/IAEA Consultants'  
Meeting held in Foz de Iguacu, Parana, Brazil  
on 16 – 18 August 2003**

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**JOINT FAO/IAEA DIVISION  
OF NUCLEAR TECHNIQUES IN FOOD AND AGRICULTURE**

**INTERNATIONAL ATOMIC ENERGY AGENCY  
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS**

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**Integrated Soil, Water and Nutrient  
Management in Conservation Agriculture**

Report of the FAO/IAEA Consultants' Meeting  
held in Foz de Iguaçu, Parana, Brazil on  
16 – 18 August 2003

**Scientific Secretary: P. Chalk  
Soil and Water Management & Crop Nutrition Section**

**Working Material Produced by the IAEA  
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## INTRODUCTION

The Consultants' Meeting (CM) was organized in close consultation with the Land and Water Development Division (AGL) of FAO. Five Consultants from Australia, Brazil, India, Kenya, and the USA, and two IAEA staff participated in the CM. The list of participants is given in Annex 1.

The CM immediately followed the Second World Congress on Conservation Agriculture (WCCA), held at the same venue (Rafain Palace Hotel, Foz de Iguacu), August 11 – 15, 2003. The two IAEA staff and three of the Consultants also participated in the 2<sup>nd</sup> WCCA. The WCCA set the scene for the CM, reviewing worldwide adoption and impact of CA practices, case studies, farmer experiences in all regions, socio-economic and political factors, barriers to adoption, and organisations/institutions involved in CA research and development activities. The WCCA attracted approximately 1000 participants from all regions, including stakeholders from Government, NARS, international donors (GTZ, CIRAD, World Bank, IICA), intergovernmental organizations (FAO, IAEA), the CGIAR (CIMMYT, IRRI), NGOs, farmers and manufacturers of direct-drill equipment. Several Divisions of FAO (including the Joint FAO/IAEA Division) provided financial support to the 2<sup>nd</sup> WCCA, which was organized by the Brazilian Federation of No-till Farmers (FEBRAPDP). The Scientific Secretary is grateful to the Federation for organizing a Meeting Room and facilities for the CM.

The objectives of the CM were:

- (i) To review current knowledge concerning the optimal management of external inputs and natural resources under conservation agriculture (CA) practices
- (ii) To define research priorities in conservation agriculture
- (iii) To define the role of nuclear techniques in research in conservation agriculture
- (iv) To draft a Project Document for an FAO/IAEA Co-ordinated Research Project (CRP) in Conservation Agriculture (2005 – 2009).

The Scientific Secretary opened the CM and provided an overview of the activities within the Soil and Water Management & Crop Nutrition (SWMCN) Sub-programme. The Consultants and the IAEA staff member made oral presentations. The Consultants from Australia and the USA each made two presentations. The programme of the CM is given in Annex 2.

The Consultants' provided overviews of past and current work on zero- vs. conventional tillage, in particular carbon and nutrient (N and P) dynamics, water balance and soil physical properties. Summaries of the presentations are given in Annex 3. The Consultants identified research priorities within CA and the role of nuclear techniques in research on CA. Conclusions and Recommendations were formulated, and a proposal for a new Co-ordinated Research Project (CRP) on CA was drafted. The draft Project Document is given in Annex 4. Thus, the objectives of the CM were fully achieved.

## CONCLUSIONS

The Consultants concluded that:

- Conservation agriculture (CA) embodies the following principles: maintenance of a continuous soil cover through surface retention of all crop residues, reduced or zero tillage, cover/green manure crops, crop rotations (including both annual and perennial species).
- CA has potential application in all agroecological zones.
- Many positive benefits are claimed for CA: reduced soil erosion, improved soil fertility (physical and nutritional), better water infiltration, SOM accumulation, reduced soil compaction, higher CEC, better WHC, increased soil biodiversity, resilience to climate change, greenhouse gas mitigation, all of which interact in a complex way to increase agricultural productivity and system sustainability. However, there is a paucity of experimental data to support many of these claims.
- The net effect of CA on greenhouse gas mitigation and long-term soil C sequestration are not well understood.
- The potential disadvantages of CA are seldom mentioned and in some cases are not well documented or understood. e.g. requirement for expensive direct drill equipment, higher management skill levels, lower soil temperatures, weed and disease control.
- Increased resource use efficiency, water use efficiency (WUE) and fertilizer use efficiency (FUE) is not presently seen as an objective of CA.
- There is a high level of interest in CA and increasing adoption of CA practices worldwide, but the geographical distribution is uneven. Future growth areas for CA dissemination/adoption exist in Asia, Africa, Central America and Europe.
- Socio-economic barriers to the wider adoption of CA are poorly understood for many areas.

## RECOMMENDATIONS

The Consultants recommended that:

- The Agency should support national / regional / international efforts to gain a better understanding of CA practices through research and capacity building.
- Research should be supported through a CRP according to the Project Document in Annex 4.
- Specifically, there is a need for experimental data to
  - Define the factors affecting OM accumulation under CA
  - Quantify interactions between organic matter accumulation and water and nutrient availability
  - Quantify the efficiency of use of external inputs to soil (e.g. water, fertilizers)
- Research Contract Holders should be scientists already conducting research in Conservation Agriculture so that the planned activities in the CRP can be fully

integrated into existing experiments. Experience in the use of nuclear techniques will be required.

- Wherever possible, the CRP should operate within existing research networks (e.g. AfNET) to optimize resources and obtain maximum synergy.
- The Project Officer of the CRP should attend the 3<sup>rd</sup> World Congress on CA (Kenya 2005) to keep abreast of the latest developments.

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## PROGRAMME

**Saturday, 16 August 2003**

09:00 – 09:45	Official Opening and Welcome  <b>Phillip Chalk</b> (Scientific Secretary, IAEA) The Soil and Water Management & Crop Nutrition Sub-programme.
<b>Session I</b>	<b>Chairperson: Phillip Chalk</b> (IAEA)
09:45 – 10:30	<b>Dr. Robert Boddey</b> (EMBRAPA, Brazil) “Necessity for external N inputs to build soil organic matter under zero tillage systems”
10:30 – 11:00	Coffee Break
11:00 – 11:45	<b>Dr. Ram Dalal</b> (QDNRM, Australia) “Carbon sequestration, nitrous oxide emission and nitrogen management in soil under no-till cropping system”
11:45 – 12:30	<b>Dr. Raj Gupta</b> (CIMMYT-India) “Managing crop residues and nutrients in permanent no-till and furrow irrigated-bed planted rice-wheat systems of South Asia - Some experiences”
12:30 – 14:00	Lunch Break
<b>Session II</b>	<b>Chairperson: Dr. Robert Boddey</b> (EMBRAPA, Brazil)
14:00 – 14:45	<b>Dr. Keith Paustian</b> (CSU, USA) “Field measurement and modeling of soil organic carbon in no-till experiments in the USA”
14:45 – 15:30	General Discussion of C and N dynamics under CA. Definition of research priorities.
15:30 – 16:00	Coffee Break
16:00 – 16:45	<b>Rebecca Hood-Nowotny</b> (IAEA) “The use of stable isotopes for the assessment and optimisation of conservation agriculture”

16:45 – 17:30

**Dr. Bernard Vanlauwe** (CIAT/TSBF-Kenya)  
“Interactions between organic resources and mineral inputs  
in the context of conservation agriculture”

**Sunday, 17 August 2003**

**Session III**

**Chairperson: Dr. Bernard Vanlauwe** (CIAT/TSBF-Kenya)

09:00 – 09:45

**Dr. Ram Dalal** (QDNRM, Australia)  
“Phosphorus and water management in soil under no-till  
agriculture”

09:45 – 10:30

**Dr. Keith Paustian** (CSU, USA)  
“Effects of tillage on soil aggregate dynamics and soil  
organic matter fractions”

10:30 – 11:00

Coffee Break

11:00 – 11:45

General Discussion on water, soil structure and nutrient  
cycling (other than C and N) under CA. Definition of  
research priorities.

11:45 – 12:30

Formulation of Conclusions and Recommendations of the  
CM

12:30 – 14:00

Lunch Break

**Session IV**

**Chairperson: Rebecca Hood-Nowotny** (IAEA)

14:00 – 15:30

Formulation of project document: project title and  
background situation analysis including justification for  
Agency’s involvement

15:30 – 16:00

Coffee Break

16:00 – 17:30

Formulation of project document: overall and specific  
objectives, expected research outputs and action plan

**Monday, 18 August 2003**

**Session V**

**Chairperson: Phillip Chalk (IAEA)**

09:00 – 10:30	Formulation of project document: Inputs, assumptions, and logical framework
10:30 – 11:00	Coffee Break
11:00 – 12:30	Formulation of project document: Logical framework
12:30 – 14:00	Lunch Break
14:00 – 15:30	Finalization of project document Closing of Meeting

## SUMMARIES OF PAPERS PRESENTED

### 1. Necessity for external N inputs to build soil organic matter under zero tillage systems

Robert Boddey, Claudia Sisti, Lincoln Zotarelli, Bruno Alves and Segundo Urquiaga  
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In our work on nitrogen cycling in different crop rotations under zero tillage (ZT) and conventional tillage (CT), it became apparent from initial studies that crop rotations which included winter leguminous green-manure crops were those under which there appeared to be the largest accumulation of soil organic matter (SOM). For this reason we concentrated our studies on quantifying inputs from biological nitrogen fixation and quantities of nitrogen exported in grain in each rotation in comparison with the differences in SOM stocks between the two tillage systems. Our most detailed study was performed at the field station of the Embrapa Wheat research centre in Passo Fundo in the State of Rio Grande do Sul on an long-term (13 year) experiment which compared three crop rotations under ZT and CT on an Oxisol with a high clay (Sisti et al., 2003).

The principal method utilised to quantify the BNF inputs was the  $^{15}\text{N}$  natural abundance technique (Shearer and Kohl, 1986). To apply this technique it is necessary to a) measure the  $^{15}\text{N}$  natural abundance ( $\delta^{15}\text{N}$ ) of the legume crop, b) to determine the  $\delta^{15}\text{N}$  of the plant-available soil N from the  $^{15}\text{N}$  abundance of non-leguminous weeds in the experimental plots, and c) the  $^{15}\text{N}$  abundance of the legume crop when grown solely on BNF (known as the 'B' value). In the plots of the Passo Fundo study the proportion of N derived from BNF (%Ndfa) by soybean was estimated to be between 89 to 98 %. These results suggested that the soybean crop removed extremely small quantities of N from the soil, while other observations led us to believe that these values of %Ndfa were overestimates. The 'B' value used in our calculations (-1.3 ‰) was derived from a mean of several values in the literature, but none of these 'B' values had been obtained from studies performed on Brazilian varieties of soybean or using the *Bradyrhizobium* strains used for inoculants in this country. A subsequent specific study to determine 'B' values for a Brazilian variety of soybean (cv. Celeste) inoculated with either the *B. japonicum* strain, CPAC 7, or the *B. elkanii* strain, 29 W, revealed that 'B' values for aerial tissue of these two strains were, respectively, -2.5 and -4.5 ‰ (Okito, Alves, Urquiaga, Boddey, submitted), and if either of these values were used to calculate the %Ndfa to the soybean the estimates were reduced to between 79 and 52 %.

Another problem in the evaluation of the contribution of BNF to the system was the difficulties involved in estimating quantities of N, which are deposited in the soil by legumes in the form of root exudates and senescent roots (non-recoverable root N). Recent work in Australia using a  $^{15}\text{N}$  leaf labelling technique has suggested that these contributions for other legumes could be very significant (Russell and Fillery, 1996;

Khan et al., 2003). Using this same technique it was estimated that while only 2 % of all plant N was found in the roots at the mid-pod-fill stage of plant growth, 21 % of all plant N was lost to the soil in the form of non-recoverable root N.

While it is apparent that considerably more work needs to be done on both the quantification of BNF using the  $^{15}\text{N}$  natural abundance technique, and the evaluation of non-recoverable root N, as the proportion of plant N exported in grain is approximately 80% for soybean, it is probable that this crop leaves little residual N for the nutrition of subsequent crops or for the building of soil organic matter. When the  $^{15}\text{N}$  natural abundance was applied to quantify the BNF input to the vetch crop the data indicated that between 77 and 87 % of plant N was derived from BNF. As none of this N was exported from the field, there was an overall N contribution to the soil/plant system in the rotations containing this crop of at least  $80 \text{ kg N ha}^{-1}$ .

The stocks of C and N total in the soil after 13 years of continuous wheat/soybean were not significantly different between ZT and CT management, but in the Rotations 2 and 3 which contained vetch and maize, the stocks of C and N under ZT were higher than under the continuous wheat/soybean and also higher than the same rotations under CT. It was interesting to note that between 46 and 68 % of this difference in C stock, respectively, were found in the depth interval of 30 to 85 cm, which suggested that there were more crop roots at this depth under ZT than under CT. Two other long-term experiments at the same site also showed the benefit of leguminous green manures to SOM stocks. In one experiment where there was only one rotation, stocks of C (0-100 cm) after 9 years of the rotation vetch/maize - oats/soybean - barley/soybean under ZT were  $18 \text{ Mg ha}^{-1}$  higher than under CT management. In the other experiment where different rotations were compared only under ZT, 9 years after installation the two rotations containing vetch or other leguminous green-manure crops again showed significantly higher C stocks than under continuous wheat/soybean.

In a further study at the Passo Fundo site, the  $^{13}\text{C}$  natural abundance of the soil samples was measured. Employing a model developed by Balesdent et al. (1990) to estimate the  $^{13}\text{C}$  abundance of the SOM prior to installation of the experiment, the results indicated that under ZT the three different rotations made no difference to rate of degradation of the original SOM derived from the native vegetation (Sisti et al., 2003). However, under CT the inclusion of the winter legume in the rotation stimulated the decomposition of the native SOM, and it was this loss of native SOM which was principally responsible for the lower C stocks observed under these two rotations under this tillage system.

From these studies we can make the following conclusions:

1. Soybean can derive high proportions of its N requirement from BNF, but the very large proportion of N exported in the grain means that there is rarely a very significant residual contribution of N to the soil/plant system.
2. To build SOM under ZT it is essential to have a positive N balance for the soil/plant system over time. In our case this input of N was derived from BNF by a winter green-manure legume in the rotation.

3. In some cases considerable quantities of SOM can be accumulated at depth (>30 cm) under ZT, which are not present under CT.
4. It appears that as under ZT the soil is not significantly disturbed, the SOM present prior to the installation of this system degrades more slowly than under CT, and the rate of decomposition of this original SOM is not affected by the presence of different crop species in the rotations.

## References

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## **2. Carbon sequestration, nitrous oxide emission and nitrogen management in soil under no-till cropping system**

Ram Dalal and Weijin Wang

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No-till practice is increasingly being used for crop production around the world. In Australia and Brazil, the current area under no-till practice exceeds 30% (8 million ha and 14 million ha, respectively), while for the USA, more than 15% (20 million ha) and worldwide 72 million ha of the total grain cropping area is under minimum and no-till practice (Benites et al. 2003). While the primary incentives are for erosion control, moisture conservation, timely operations, and reduced operation costs for machinery and fuel, there are a number of potential benefits including aggregation, fertility maintenance, enhanced biotic activity, carbon sequestration and nitrogen cycling. The potential risks include herbicide resistance and environmental pollution, pests, cooler soil in early spring in temperate region thus delaying field operations, and increase in nitrous oxide emissions due to wetter soil conditions and slower plant N uptake after sowing.

No-till (NT) cropping systems involve the absence of tillage operations except for sowing of crops. Frequently, but not always, crop residues are retained on the surface. This creates different soil surface microenvironment under NT from that of conventional till (CT) system. Carbon sequestered is more stratified in the soil profile in NT than CT. More water enters the soil and less soil erosion occurs in NT than CT. This has a positive response in semi-arid environments and in clayey soils, where more plant available water is stored in the soil profile for crop use in NT than CT. In mesic and humid environments, however, there is potentially greater leaching of nutrients in the former as well as it also results in wetter soils, especially in cooler environments.

As a consequence, there is likely to be increased nitrous oxide emission in NT than CT. The net impact of NT on the greenhouse gas (GHG) emission is the net result of C sequestration (GHG mitigation) and nitrous oxide emission (296 times CO<sub>2</sub>-equivalent emission) (Table 1), and possibly methane oxidation/emission. For example, in a Vertisol 33 years of NT practice in combination with N fertiliser application enhanced carbon sequestration. Nitrogen management in NT cropping system becomes critical not only for enhancing N use efficiency and water use but also for GHG abatement in the long term. There are limited datasets available on nitrous oxide emission (in Table 1, IPCC Guidelines, 1.25% of fertiliser N applied) and methane emission or sink in soil under NT practices. The use of <sup>15</sup>N techniques would elucidate the mechanisms and quantify the sources and proportion of N<sub>2</sub>O production from soil, applied fertilisers, legume N and organic N sources.

Table 1. Greenhouse gas budget ( $t\ C\ ha^{-1}$ ) for different tillage and N fertilisation scenarios on a Vertisol in SE Queensland, Australia (sampled in March, 2001) (W Wang, RC Dalal, unpublished data).

Tillage	N fertiliser	TOC in soil 0-10 cm	Stubble C	Diesel consumption C	N <sub>2</sub> O from fertilization (C-equivalent)	C balance	$\Delta C^*$
CT	N0	21.5	0.8	-0.7	0	21.6	0
	N69/90	23.3	0.8	-0.7	-3.5	20.0	-1.6
NT	N0	21.8	1.0	-0.2	0	22.6	1.0
	N69/90	25.0	1.2	-0.2	-3.5	22.6	1.0

\* Relative greenhouse mitigation potential using the net C flux under CT + N0 as the benchmark.

### **Nitrogen and water management**

Nitrogen use increases water use efficiency (WUE) from soil under NT more than that from CT although in a dry crop growing season in a semi-arid environment it is maintained under NT but greatly reduced under CT.

### **General principles of N management** (Laegreid et al., 1999; Dalal et al., 2003)

- Apply fertiliser N at optimum rates by taking into account all N sources available to the crop/pasture from soil (ammonium and nitrate N in the soil at the time of crop sowing, and in-crop N mineralisation), and other N sources such as manure or waste.
- Apply fertiliser N at the rate and time to meet crop/pasture needs and development stage, and when appropriate through split application.
- Avoid fertiliser N application outside the crop/pasture growing season, and especially prior to a clean fallow period. Avoid fallow periods if season or availability of irrigation permits.
- Provide fertiliser N application guide through crop/pasture monitoring and soil tests, and adjust fertiliser application rates and timing accordingly.
- Apply other nutrients if required so that nutrients supply to crop/pasture is balanced and N utilisation is optimised.
- Avoid surface application so that fertiliser N losses are minimised and plant utilisation maximised. Apply band placement or point placement close to the plant roots such as under NT practice.
- Monitor and adjust fertiliser application equipment to ensure the precision and amount of fertiliser applied, and control over appropriate spatial distribution (Global Positioning System/Geographical Information System) according to the information from yield monitors, crop/pasture monitors (including remote sensing), and soil tests.
- Fertiliser should be in a form (such as granulated) that can be applied evenly, conveniently and cost-effectively. In irrigated agricultural systems, application in sprinkler/drip irrigation may be an effective option.
- Fertiliser may be formulated with urease and/or nitrification inhibitors or physical coatings to synchronise N release to that of crop/pasture growth needs so that at any given time minimum amount of mineral N (ammonium and nitrate) is present in soil.
- Practice good crop/pasture management, disease control and good soil management to optimise crop/pasture growth and hence efficient fertiliser N utilisation. Avoid/or reduce cultivation early in the fallow period and retain plant residues to minimise mineralisation and nitrate accumulation during the fallow period.
- Use cover crops to utilise the residual mineral N following N-fertilised main crops or mineral N accumulation following legume-leys.

## Challenges

- In most NT systems in Australia, there is only marginal C sequestration benefit (Dalal and Chan 2001; Chan et al. 2003) compared to the CT practice. This is because of the marginal increase in biomass production and hence similar carbon inputs. The challenge is to increase biomass production by maximising water use efficiency and nutrient efficiency, and minimising crop diseases.
- Net greenhouse gas benefits must consider all the energy inputs, including fertiliser N and fuel for considering GHG mitigation for the NT practice. There is limited information available on nitrous oxide emission and/or methane emission/sink for the tropical NT systems.
- Optimum water and nutrient management for NT systems is the key to enhance GHG benefits, improve productivity and maintain the quality of natural resources.

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### **3. Managing crop residues and nutrients in permanent no-till and furrow irrigated-bed planted rice-wheat systems of South Asia - Some experiences**

Raj Gupta  
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Rice-wheat systems occupy more than 13.5 m ha in South Asia. Consortium partners are engaged in developing new resource conserving technologies (RCTs) to save on water, improve resource use efficiency and reduce costs of production. These technologies include developing a permanent system of no-till in flat and raised bed- furrow irrigation (FIRB) systems, together now occupying more than 500,000 hectares in South Asia. Efforts are going on to meet challenge of making the no-till and FIRB systems more permanent and with minimal disturbance and be able to plant wheat, rice and other crops year after year. Farmers in the sub-continent are still experimenting with these systems to fully appreciate the potential of these technologies in terms of enhancing and sustaining rice-wheat cropping systems and its diversification with more remunerative crops.

Major constraints in the way of adoption of CA is non-availability of crop residues and scarcity of irrigation water in the peak summers for growing green manure crops, possibly the only time window available for growing them. It is gradually becoming more apparent that potassium deficiency will soon emerge as a major threat in SA. It seems that the only strategy to meet the challenge is through management of crop residues. Loss of soil organic matter is one of the recognized threats to rice-wheat sustainability.

From the presentation and the ensuing discussions following conclusions can be drawn:

- Techniques for planting into loose residues should be developed for south Asian farmers.
- Additional research will be needed for managing N and K requirements of the crops.
- There is a need to diversify the rice-wheat cropping system through incorporation of green manure and grain legume crops and growing more remunerative crops to substitute for rice/ wheat that require less water and external inputs.

#### **4. Field measurement and modeling of soil organic carbon in no-till experiments in the USA**

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No-tillage management was first applied in the US nearly 50 years ago, but adoption of no-till on a significant area of US cropland has only occurred during the past 2 decades. Adoption rates were most rapid from the mid 1980s to mid 1990s, driven in part by governmental programs stressing conservation compliance. Adoption to date has been greatest in the Midwest corn-soybean belt and in the Chesapeake and northern piedmont areas in the eastern US. Use of no-till was motivated initially as an erosion control measure and that is still a dominant justification, along with labor and energy savings compared with conventional tillage. No-till use in semiarid regions (e.g. Great Plains), by helping to conserve water, provides opportunities to intensify crop rotations and eliminate bare summer-fallowing. More recently, interest in no-till as a means to promote carbon sequestration as a greenhouse gas mitigating strategy has gained attention.

A number of long-term experiments in the US include alternative tillage treatments, the oldest such experiments having been in place for nearly 40 years. Over the past few years our research group has conducted cross-site sampling and analysis in such experiments, including about 20 locations that compare no-till with more intensive systems such as moldboard plowing. The data provide an opportunity to make more robust regional analyses of tillage effects since sampling methods, soil preparation and analysis were conducted using uniform methodology.

At most sites, significant differences in soil C stocks between no-till and intensive tillage were found and where significant differences were detected C stocks were in all cases higher under no-till. At some sites where annual rates of C addition in residues varied as a function of rotation or fertilization treatments, no-till systems were 'upshifted' (showing roughly similar differences in C stock change), suggesting weak or no interaction between tillage effects and C input rates [This is contrary to theoretical predictions (see below) of increasing soil C differences as C input rates increase]. However, the number of sites with differing input rates, uncertainty in the measurements and a relatively small range in C input rates within a given site, make this interpretation uncertain. In contrast, plotting soil C difference (between no-till and plow systems) as a function of large regional scale differences in water availability (which should be closely correlated with productivity and C input rates) suggests a trend of increasing soil C differences as water availability (and productivity) increase. However, between site differences in crop species and soil properties are likely to confound the relationship.

Modeling using the Century ecosystem model has been done at most of the long-term sites, including those with tillage treatments. Model evaluation has been done using a single, uniform parameterization for all sites (i.e. the model was not calibrated at

individual sites). In general model performs poorer in predicting the effects of different tillage treatments than for other management variables (e.g. crop type, rotation, fertilization, manure addition). Four sites were selected to illustrate particular issues and types of model failure in predicting effects of no-till on soil C stock changes.

The Century model represents tillage effects on soil C dynamics on the basis of three hypothesized mechanisms: 1) decomposition rates of surface residues is lower than for buried residues (due to a less favorable environment for microbes) conditions, 2) the stabilization efficiency (i.e. proportion of decomposition products not evolved as CO<sub>2</sub>) of surface residues is higher than for buried residue and 3) tillage causes a transient increase in the decomposition rate for each of the SOM pools (simulating increased substrate availability for microorganisms).

Model results at Sidney, Nebraska where native sod was converted to wheat-summer fallow cropping, under intensive, moderate and no-till tillage systems, show good agreement with measured trends. However, the substantial variability in measurements from year to year, due to spatial variability, variability due to different operators, sampling and soil preparation, illustrate the difficulties in evaluating model performance in many field experiments.

At Wooster, OH, in a silt loam soil with plow and no-till treatments, for three crop rotations, the model substantially *overpredicts* differences in soil C associated with tillage. Soil C in treatments under plow tillage appears to be declining while the model predicts them to be roughly at steady state. Measured soil C under no-till suggests the systems are maintaining stocks but not increasing as simulated in the model. Estimates of C inputs estimated from measured harvest yields suggest model is probably underpredicting C inputs, especially in no-till, and thus this is not the likely source of model failure; rather the representation of tillage effects on soil dynamics is insufficient.

In contrast, for the same crop rotations and tillage treatments in a clay soil at Hoyteville, OH the model tends to underpredict differences in tillage on soil C stocks. Simulated C yields appear to be higher than actually occurring in the field, indicating again that the primary source of model failure is again in the representation of tillage effects on SOM dynamics. It appears likely that the interaction of tillage disturbance with soil texture and physical properties is a key relationship requiring more knowledge to improve the predictability of changes in SOM under different tillage regimes.

Finally, at Lexington, KY, where blue-grass sod was converted to continuous corn with plow versus no-till treatments, the data suggest a rapid initial decline in SOM in both systems, with a subsequent recovery and build up of soil C under no-till versus stabilization of soil C at a lower level under the plow treatment. The model predicts a more gradual decline in SOM with conventional treatment vs a slow increase under no-till. The increase rate modeled under no-till is similar to that measured but the sharp initial decline in both systems following conversion from grassland to annual cropland cannot be adequately captured by the model.

Next steps for research include compiling additional data from long-term experiments on tillage responses along gradients in climate and soil conditions, to better define their interactions and controls on soil C turnover. Alternative model assumptions, such as tillage-event driven transfers from physically protected pools to ‘unprotected pools’, may be better able to represent the ‘hysteresis’ behavior often exhibited by SOM (i.e. contrasting losses vs. accumulation trajectories). Where opportunities exist, the use of natural abundance  $^{13}\text{C}$  methods to quantify rates of change for SOM derived from different sources (e.g. following land use changes) can help constrain model interpretations and test alternative formulations.

Summary conclusions:

- No-till generally increases soil carbon relative to intensive tillage (sometimes by maintaining vs losing C).
- Some evidence for an additive ‘upshift’ interaction between tillage effects and C inputs, within a given soil/climate regime.
- Regionally, no-till effects on soil C may increase (linearly?) with increasing H<sub>2</sub>O availability (C input gradient?).
- High field variability, variation in sampling and analysis, and uncertainty in initial conditions make model evaluation/falsification difficult in many instances.
- Data on C inputs is key to evaluating model failures.
- In general, prediction of tillage effects on SOM is more difficult than for other management variables (e.g. rotations, fertilization, manure addition.)
- ‘Hysteresis’ behavior in response to tillage vs. cessation of tillage is not well represented by simple changes in  $1^0$  rate constants.
- Better understanding of role of texture and mineralogy on tillage responses.
- Promising avenues for future work include:
  - ◆ Measurements of soil C dynamics, across climate and soil gradients, to refine interactions and control mechanisms.
  - ◆ Representing tillage disturbance as an ‘event-driven’ transfer from physically-protected pools to unprotected pools as a function of tillage intensity and soil physical properties
  - ◆ Testing models based on more functional, measurable pools; use of  $^{13}\text{C}$  natural abundance, possibly  $^{14}\text{C}$  dating, as a component of model evaluation.

## 5. The use of stable isotopes for the assessment and optimisation of conservation agriculture.

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FAO is engaged in the development of methodologies and tools to analyse win-win options for small farmers aiming at preventing land degradation, enhancing soil fertility, land productivity and carbon sequestration, which contribute to mitigating atmospheric CO<sub>2</sub> levels (1). The conversion from conventional tillage to no-tillage (zero tillage)/conservation agriculture has been suggested as one possible win-win option.

Nuclear techniques in particular stable isotopes are extremely useful in the analysis and assessment of the nutrient, water and carbon, inflows and outflows of such complex farming systems. With international networks of experienced scientists and the capacity to train and develop further expertise, the FAO/IAEA is in a unique position to coordinate a global research programme to assess and optimise conservation agriculture

<p><b>Strengths</b></p> <ul style="list-style-type: none"> <li>•Experienced international groups working over a range of agro-ecosystems.</li> <li>•Common resource, common research goal.</li> <li>•Equipment and expertise for stable isotope analysis in Vienna.</li> <li>•Experienced staff available for training.</li> <li>•Quality assurance: good experience.</li> </ul> <p>Use of stable isotopes, no postal restrictions.</p>	<p><b>Opportunities</b></p> <ul style="list-style-type: none"> <li>•To obtain global data over a range of agro-ecosystems for modelling and policy making purposes.</li> <li>•To develop win-win scenarios using isotope techniques.</li> <li>•To interchange experience and knowledge of techniques.</li> <li>•To test and validate new techniques.</li> <li>•To strengthen capacity in stable isotope techniques.</li> </ul>
<p><b>Weaknesses</b></p> <ul style="list-style-type: none"> <li>•Availability of mass spectrometers for analysis on site.</li> <li>•Some groups may require additional training and capacity building.</li> <li>•Uncertainties in techniques.</li> </ul>	<p><b>Threats</b></p> <ul style="list-style-type: none"> <li>•Too high tech, implementation problems.</li> <li>•Relevance and applicability of results.</li> </ul>

systems. A preliminary SWOT analysis was done to explore the issues of undertaking a CRP in this area.

The Soils Unit in the FAO/IAEA Laboratory, Seibersdorf, has a range of backup services to offer the CRP, including, quality assurance, isotope analysis and training. In addition the Unit has over 30 years institutional experience of conducting isotope experiments in developing countries. The Unit has conducted extensive research in the areas of: inorganic fertilizer usage, biological nitrogen fixation, measurement of plant N uptake

from organic residues, measurement of soil water, and more recently in the areas of: below ground N, carbon cycling, using of the isotopes of water. A number of methods and techniques, which could potentially be used to study conservation agriculture practices will be presented.

## 6. Interactions between organic resources and mineral inputs in the context of conservation agriculture

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Conservation Agriculture (CA) advocates the implementation of 3 principles for sustained and environmentally beneficial farming: (i) reduced tillage, (ii) continuous soil cover, and (iii) appropriate rotations. The Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT) organizes its research agenda around 5 major outputs of which 3 are closely linked to the principles of CA: (i) managing nutrient and soil organic matter (SOM) dynamics, (ii) managing belowground biodiversity, and (iii) enhancing ecosystem services. All TSBF-CIAT activities are implemented through the African Network for Tropical Soil Biology and Fertility (AfNet), a consortium of national partners from universities and agricultural research centres that momentarily has over 200 members from all over Sub-Saharan Africa (SSA). AfNet implements multi-locational network activities around specific research themes to which CA has been added recently. Examples of activities in the field of CA are: (i) reduced tillage for tef production systems in Northern and Central Ethiopia, (ii) rotational and residue management impacts on maize, sorghum, and millet production in Burkina Faso and Niger, and (iii) appropriate grain and herbaceous legume rotations in Kenya and Uganda.

CA potentially creates positive interactions between soil retention, water use efficiency, nutrient dynamics, and other crop growth factors, resulting in enhanced crop production and environmental quality. In this paper, we will focus on potential interactions between organic inputs, SOM, and fertilizer. The combined application of organic inputs and fertilizer is currently accepted as the way forward in boosting crop production in SSA because either of the two inputs is usually available in short supply and because the combined application can potentially generate added benefits in terms of crop production or soil fertility improvement through positive interactions between both inputs. A *Direct* and *Indirect Hypothesis* can be formulated around such interactions (Vanlauwe et al., 2001a).

The *Direct Hypothesis* states that temporary immobilization of applied fertilizer N may improve the synchrony between the supply of and demand for N and reduce losses to the environment. The *Indirect Hypothesis* states that any organic matter-related improvement in soil conditions affecting plant growth (except N) may lead to better plant growth and consequently enhanced utilization of the applied fertilizer N. The latter hypothesis could apply both in the short term, after one or a few organic input applications, or in the longer term through an improved SOM status.

Data from various trials provide information supporting the *Indirect Hypothesis* in the short term:

(i) in the Sahel, applying crop residues with fertilizer significantly enhanced N use efficiency of the applied fertilizer (Figure 1);

(ii) in Southern Togo, adding organic matter with urea was observed to improve the use efficiency of the N fertilizer caused by improved soil water conditions during maize grain filling (Vanlauwe et al., 2001b), and  
(iii) in Western Kenya, organic resources were observed to enhance the available P status that may potentially foster the recovery of applied fertilizer N (Nziguheba et al., 2000).

The SOM pool regulates a series of functions or properties, e.g., water retention, cation exchange properties, or buffer capacity that may also lead to better nutrient use efficiency of fertilizer. SOM also release N through decomposition and may act as an additional source of N. In a long-term alley cropping trial in South-western Nigeria, SOM was observed to mainly act as a source of N and increase in total crop N uptake could be explained in relation to the A-value of the soil and the amount of N added (Diels et al., 2002). On the other hand, in a multilocational on-farm microplot study in Southern Benin Republic, a higher SOM content enhanced the use efficiency of applied urea-N (Vanlauwe et al., unpublished results).

One CA system that deserves efforts in quantifying the mechanisms governing its functioning is the Quesungual farming system currently adopted by over 6,000 farmers in Southern Honduras. This system is an alternative to slash-and-burn in dry tropical forests, and involves no burning of aboveground biomass at field preparation, direct sowing, selective pruning of native vegetation, and mulching. Reported advantages are: a high species diversity, high resilience to extreme water deficits (El Niño, 1997) or excesses (hurricane Mitch, 1998), the possibility to intensify and diversify the farming systems (e.g., introduction of vegetables, cash crops, livestock), reduced production costs due to labour (e.g., for weeding), and increased average maize yields (preliminary estimates show yield improvements over 80%). Some specific research themes to be addressed in this system are: clarification of the impact of tree density vs. surface mulch, assessment of the water balance and interactions with nutrient use, above and belowground biodiversity, SOM build-up and quality, and the boundary conditions for scaling up the system.

In conclusion, lots of efforts are currently being implemented to demonstrate and disseminate CA in various areas in the tropics, and specifically in Central America and SSA. These efforts are usually not backstopped by a clear understanding of the functioning and relative importance of the impacts of the 3 principles on the farming systems. Issues that should receive special attention are (i) the interactions between water and nutrient use efficiencies, (ii) SOM dynamics and the impacts of an enhanced SOM status on functions regulating crop growth, (iii) niches for implementation of CA taking into account variability in biophysical and socio-economic conditions at the farm and community level, and (iv) impact of CA on the abundance and composition of belowground biota.

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## 7. Phosphorus and water management in soil under no-till agriculture

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Under no-till conservation agricultural practices, crop residues are returned to the soil's surface whereas under conventional tillage they are mixed within the top ploughed layer (5-20 cm depth). Moreover, P fertilizer drilled in the soil at sowing of the previous crop is also mixed in ploughed soil while in NT it concentrates in rows or slits, usually near the soil surface. Generally, this results in the stratification of phosphorus with depth under NT more than under CT.

In a semi-arid region, where topsoil layer remains dry for prolonged periods during crop growth, the possibility exists that plant roots may not be able to access the fertiliser P stranded in the dry layer. For example, Strong *et al.* (1997) showed that residual fertiliser value of P applied in the previous year was only 20-40% under low soil water regime to that of well-watered soil. However, water use efficiency increases as the P application increases in P responsive soils. Water use efficiency is generally higher under NT than CT practice in semi-arid regions (Gibson *et al.* 1992; Norwood 1999).

In spite of these findings, with adequate P fertilisation of crops, the drying of the topsoil layer does not appear to be a limiting factor for crop production (Weil *et al.* 1988). On the other hand, repeated P application in a limited area of soil and without further mixing with soil under NT results in enhanced P uptake and greater grain yields (Hargrove 1985). Controlled traffic under NT practice may prove to be even more beneficial in soils with high P sorption capacity since only the limited soil volume is fertilized.

Where P is limiting, P cycling through crop residue becomes important in supplying P to crops (Dalal, 1979) since it delays the precipitation of inorganic P as well as organic P as stable P-aluminium precipitates (Shang *et al.*, 1996) as well as crop residue contains significant amount of P immediately available to crops. Thus, crop residue addition increases L value. However, crop residue P had greater effects on soil with lower than on that with higher P-sorption capacity (Umrit and Friesen, 1994). Under NT the crop residue is concentrated on the soil surface and this more effectively reduces the soil interaction of P from the plant residues than that under CT where crop residues are mixed with the soil. In the latter, enhanced P immobilisation could occur, especially in high P-sorption soils (Salas *et al.*, 2003).

The forms of soil P are less affected by tillage practice. In general resin extractable inorganic P in soil under NT is higher than that under CT practice, especially in coarse-textured soils. There appears to be methodological problem in quantifying the contribution of organic phosphorus to P availability to crops in that it is difficult to measure organic P decline in soil under cropping (Suner *et al.*, 2003) although labelled <sup>32</sup>P organic materials release P relatively rapidly into the soil solution (Frossard *et al.*, 1996). Similarly, measurement of E values could be improved by short-term isotopic

exchange (Salcedo et al., 1990; Morel et al., 2000), or using anion exchange resin (Hamon and Laughlin, 2002), especially in high P sorption soils.

### **Challenges:**

- No-till practice increases P stratification with depth; however, it is not known whether in high P-sorption soils P stratification affects P uptake and P utilisation efficiency by crops and infrequent soil mixing need to be employed or develop new cropping systems, involving rotations.
- No-till also reduces P transport in sediments from erosion although little is known about P leaching losses, especially in coarse-textured soils under NT practice.
- No-till increases WUE in most soils where P is applied although these effects are less studied in finer-textured and high P-sorption soils.
- There is some progress made in utilising P radioisotopes to elucidate P sorption and availability processes in soils of range of characteristics, when it is used in combination with ion exchange methodology. It could be further improved, especially for strategic research.
- There is currently limited use is being made of <sup>31</sup>P NMR techniques. The applicability of these techniques should be further explored in elucidating P forms in soil, their availability, and cycling in plants, soils and landscapes in order to improve P utilisation efficiency and reduce potential environmental pollution.

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## 8. Effects of tillage on soil aggregate dynamics and soil organic matter fractions

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The effects of tillage on soil structure and aggregation are well known and have been studied for many years. Less, however, is known about how changes in soil structure influence the stabilization and turnover of soil organic matter (SOM), and how these processes are affected by physical disturbance such as tillage. Our general research questions include: 1) how do soil physical properties (e.g. aggregation, texture, clay mineralogy) affect the location and form of SOM in soil?, 2) how does tillage disturbance interact with soil biophysical properties to affect SOM turnover?, 3) can mathematical models based on measurable, functional pools of SOM give better prediction of SOM dynamics?

Studies were carried out in four long-term experiments in the Midwest US, arrayed along a texture gradient including sandy loam, loam, silt loam and silty clay loam textures (Table 1). Each site has treatments contrasting continuous no-till (NT) versus intensive, moldboard plow tillage (CT) – three of the sites were under no-till for 25 year or more, while one was a more recent experiment of 7 years old. Each of the sites had a nearby long-term ‘native’ (NV) never-tilled perennial ecosystem.

Site	Soil type	Texture	MAT (°C)	MAP (mm)	Cropping	Duration (y)
Sidney, NE	Haplustoll	Loam	8.5	440	Wheat-fallow	26
Wooster, OH	Fragiudalf	Silt loam	9.1	905	Continuous corn	33
KBS, MI	Hapludalf	Sandy loam	9.2	920	Corn-soybean	7
Lexington, KY	Paleudalf	Silty clay	13.1	1130	Continuous corn	24

The basic methodology for separation of aggregate and aggregate-associated organic matter fractions uses field-moist soil which is gently broken to pass an 8 mm sieve and then air-dried. The air-dried soil is then immersed repeatedly in distilled water over a series of nested sieves (2000, 250 and 53  $\mu\text{m}$ ) to obtain four size fractions: large macroaggregates ( $>2000 \mu\text{m}$ ), small macroaggregates (250-2000  $\mu\text{m}$ ), microaggregates (53-250  $\mu\text{m}$ ), and silt+clay ( $<53 \mu\text{m}$ ). Plant material (light fraction-LF) that is not incorporated into aggregates is separated by flotation in 1.85 g cm<sup>-3</sup> sodium polytungstate liquid. The aggregates (minus LF) are then fully dispersed to obtain coarse ( $>250 \mu\text{m}$ ) and fine (53-250  $\mu\text{m}$ ) aggregate-associated particulate organic matter (+ sand), referred to as iPOM, and mineral-associated (mSOC) soil organic C.

Total carbon stocks were significantly higher under no-till at three of the sites (NE, OH, KY) but not significantly different at the MI site – possibly due to the much shorter time under no-till management. Aggregate distributions at all the sites showed similar behavior, with the native systems having the largest proportions of macro-aggregates, followed by no-till. Conventional tillage treatments had few aggregates in the largest (>2000  $\mu\text{m}$ ) and fewer small macroaggregates (250-2000  $\mu\text{m}$ ) than native and no-till. Within treatment carbon contents of aggregates for three of the sites increased with increasing aggregate size, conforming to the expected pattern of aggregate hierarchy *sensu* Tisdall and Oades. Between treatments and within an aggregate size class, C contents tended to be in the order NV>NT>CT. The Lexington site, which has a mixed clay mineralogy including significant amounts of 1:1 clays and Fe- and Al-oxides, showed quite uniform C contents, across aggregate size classes, within a treatment. This suggests that mineral-mineral binding is an important mechanism for aggregation where a mixture of negative and positive charged surfaces exist as in 1:1 and oxide colloid minerals.

The most notable difference in the aggregate-associated C fractions was a much higher proportion of fine IPOM (<250  $\mu\text{m}$ ) relative to coarse iPOM (250-2000  $\mu\text{m}$ ) in the no-till systems, and this ratio (around 2) was the same for all 4 sites. Data from  $^{13}\text{C}$  natural abundance at the Sidney site showed that there was much more crop-derived C (from organic matter inputs since 1970 when the experiment was started) associated with the microaggregate fraction in the NT system compared with CT. This and several other results support a conceptual model of C stabilization under NT in which a reduced turnover rate of soil aggregates was hypothesized as the primary mechanism for higher C stabilization under NT. Tillage disturbance acts to ‘short-circuit’ this aggregate turnover cycle, thus reducing the amount of C stabilized in microaggregates.

With further refinement of the separation methods, including a technique designed to separate stable microaggregates making up macroaggregate structures, the fractionation was applied to an additional no-till experiment in Passo Fundo in southern Brazil. The Sidney, NE, Lexington, KY, and Passo Fundo, Brazil sites constitute a gradient in clay mineralogy ranging from 2:1 montmorillinite-type clays, mixed 1:1 and 2:1 clays with some oxides at Lexington and 1:1 and Fe- and Al-oxides in Passo Fundo. Despite differences in the distribution of aggregate sizes and C concentrations across aggregate size classes, as a function of clay mineralogy, the differences between tillage systems in C contents associated with microaggregates derived from stable macroaggregates accounted for >90% of the total C stock differences (0-20 cm depth) between tillage treatments at all three sites. The findings support the hypothesis that C stabilized within microaggregate structures, formed within macroaggregates, may be the primary mechanism accounting for increased SOC accumulation under no tillage. This may form the basis for more functional, mechanistic models of SOM dynamics and the effects of tillage.

Main conclusions:

- No-till increases the proportion of large, stable aggregates.
- Carbon content as a function of aggregate size depends on soil mineralogy.
- Disturbance decreases the proportion of stable microaggregates making up macroaggregates.
- Greater amounts of microaggregate-associated C, stabilized within macroaggregates, may account for much of the difference in total C between no-till and intensive tillage systems.

## PROJECT DOCUMENT

### 1. Title of the CRP:

Integrated Soil, Water and Nutrient Management for Conservation Agriculture

### 2. Background Situation Analysis (Rationale/Problem Definition)

Of the total area of land in the world presently under arable crops (1,360 Mha – FAO, 2002) at least 225 Mha are estimated to be severely to moderately degraded (Oldeman, 1994). In tropical and sub-tropical regions, owing to higher soil organic matter (SOM) decomposition rates due to high temperatures, and in many regions increased pressure on the land due to population growth, this problem is disproportionately severe and growing more rapidly than in temperate regions. For example, it is estimated that 25 % of all degraded agricultural land is found in Africa.

With the development of effective wide spectrum herbicides in the USA during the 1960s, the first steps were made to eliminate soil tillage, and no-tillage crop production systems were developed and spread such that today 13 % of all arable crop area (22.4 Mha) in the USA is under no-till (Derpsch, 2003). In the early 1970's, in response to severe erosion problems occurring in southern Brazil where the soil was tilled twice a year under continuous wheat/soybean cropping, progressive farmers started to experiment with no-till in this sub-tropical region. Until the 1990s the spread of this system in Brazil was modest (~1 Mha in 1992), but in order to mitigate pest and disease problems most practitioners introduced more crops into the system with maize in summer and oats or green manures in winter. From trials with these systems in Brazil and elsewhere, the various management systems, which today are collectively known as Conservation Agriculture (CA) were developed.

CA depends essentially on three principal management practices: (a) Elimination or reduction of tillage, (b) year-round preservation of soil cover with crops or crop residues and (c) crop rotations including where possible contrasting crops such as cereals in rotation with N<sub>2</sub>-fixing legumes and/or Cruciferae. Today these systems occupy over a third of the cropped area of Brazil (17.4 Mha) and over half of that in Argentina (13 Mha) and worldwide amounts to ~70 Mha (Derpsch, 2003).

The benefits of the adoption of this system are unquestionable in terms of soil conservation, reduction of labour and/or fuel inputs, and other frequently observed advantages including improved soil fertility (physical and nutritional), better water infiltration, SOM accumulation, reduced soil compaction, higher CEC, better WHC, increased soil biodiversity, resilience to climate change and greenhouse gas mitigation, all of which interact in a complex way to increase agricultural productivity. There are very considerable potential benefits of CA, not only for increasing productivity and sustainability of agricultural production systems with significant off-farm environmental

benefits, but also to enhance food security for millions of smallholders in the developing world.

The rapid adoption of this system in South America, the USA and Australia has outpaced the scientific understanding of the principles of CA, and major efforts are being made by FAO, CGIAR centres, NARS of many countries, NGOs and CA farmer associations/federations to expand the adoption of CA. However, there is a deficit in the scientific understanding of the impact of the introduction of CA on nutrient and water use efficiency, SOM dynamics, control of weeds and crop disease and the interactions between them. It is essential that this lack of basic information be addressed through research, in order to develop optimal CA management practices adapted to local needs and conditions. This will provide a sound scientific basis for expansion of CA into regions (Europe, Central America, Africa, Asia) where it is not currently widespread.

The Agency's involvement is justified in that:

- a) Nuclear techniques are essential to obtain quantitative estimates of organic matter dynamics, water balance and nutrient flows in conservation agriculture systems. More specifically, the techniques that may be used include:
  - $^{13}\text{C}$  and  $^{15}\text{N}$  to quantify the stabilization and turnover of SOM
  - $^{13}\text{C}$  and  $^{15}\text{N}$  to quantify the fate of N and C in crop residues
  - $^{15}\text{N}$  to quantify legume BNF inputs to crop rotations
  - Neutron probe to profile soil water content
  - Sealed source ( $^{63}\text{Ni}$ ) to quantify  $\text{N}_2\text{O}$  emissions by ECD
  - $^{32}\text{P}$  to study the availability and sorption of P in P-fixing soils (laboratory studies)
- b) The objectives of the proposed project fall within the scope of Agency Project E.1.02 "Development of soil management and conservation practices for sustainable crop production and environmental protection" and are in line with a Major Output of the FAO's Medium Term Plan
- c) The research approaches envisaged are highly relevant to Member States of FAO and IAEA.
- d) The proposed CRP will operate within the framework of regional networks of national research institutes working in conservation agriculture. The Agency has a strong track record in the conduct of co-ordinated research networks that have successfully brought together scientists from different disciplines in both developing and developed countries. The findings from this CRP could be further disseminated through national or Regional Technical Co-operation Projects.
- e) The Seibersdorf Laboratory of IAEA has strong in-house capacity to support the CRP through training, quality assurance, analytical services, and strategic research capability.

### **3. Overall Objective**

To enhance the productivity and sustainability of farming systems through a better understanding of the principles and practice of conservation agriculture

### **4. Specific Research Objective (Purpose)**

To quantify the individual and interactive effects of conservation tillage practices, residue management, crop rotations, nutrient and water inputs to increase soil organic matter, resource use efficiency, agricultural productivity and environmental quality

### **5. Expected Research Outputs (Results)**

- Data on carbon, water and nutrient dynamics under conservation agriculture in diverse agroecosystems
- Means to extrapolate experimental findings across and between regions.
- Enhanced capacity of NARS to conduct integrated soil, water and nutrient management studies with the aid of nuclear and related techniques.
- Research findings communicated to the wider community.

### **6. Action Plan (Activities)**

- 6.1 Consultants' Meeting (August 2003). The CM Report is attached.
- 6.2 Presentation of Project Document to PCC (October 2003)
- 6.3 Advertisement of approved CRP (December 2003)
- 6.4 Research contract and agreement proposals received (February – July 2004), evaluated (August-September 2004) and approved by PCC (October 2004). Preference will be given to scientists already conducting research in conservation agriculture so that the planned activities in the CRP can be integrated into existing experiments. Experience in the use of nuclear techniques will be required. Contract proposals will be encouraged/solicited from NARS scientists in developing countries who are part of research networks or teams being supported by FAO, the CGIAR or other international funding agencies.
- 6.5 Research Contracts (10 @ US \$8,000), and Agreements (4 - 5) awarded (Jan-Feb. 2005, R0). Research contracts and agreements renewed annually in February 2006 (R1), 2007 (R2), 2008 (R3) and 2009 (R4).
- 6.6 Research will be conducted on the impact of conservation agriculture practices on productivity and the dynamics and interactions between soil carbon, water and plant nutrients, particularly nitrogen and phosphorus.
- 6.7 Scientific Secretary of the CRP to attend the 3<sup>rd</sup> World Congress on CA (Kenya 2005) to keep abreast of latest developments.

6.8 RCMs: 1st (March 2005) with training workshop at Seibersdorf Laboratories; 2nd (Sept 2006); 3rd (March 2008); 4th (Sept 2009).

6.9 Publications (TECDOC or special journal issue) 2010.

Activity	2003	2004	2005	2006	2007	2008	2009	2010
6.1	X							
6.2	X							
6.3	X							
6.4		X						
6.5			X	X	X	X	X	
6.6			X	X	X	X	X	
6.7			X					
6.8			X	X		X	X	
6.9								X

## 7. Inputs

Activity	2005	2006	2007	2008	2009	2010
Research contracts <sup>1</sup>	80 000	80 000	80 000	80 000	80 000	
Project Officer to attend 3 <sup>rd</sup> WCCA	3 000					
RCMs	30 000	33 000		33 000	30 000	
Publications						5 000
<b>TOTAL</b>	<b>113 000</b>	<b>113 000</b>	<b>80 000</b>	<b>113 000</b>	<b>110 000</b>	<b>5 000</b>

<sup>1</sup>Includes cost of isotopes and minor items of equipment

## 8. Assumptions

- Adequate inter-disciplinary teams established and field and laboratory facilities available to conduct the programmed research.
- Adequate training in nuclear techniques provided in conjunction with first RCM.
- Research not interrupted by catastrophic climatic or other events.
- Research contract obligations fulfilled.
- Agreement holders will provide strategic support to implement the main elements of the project.
- Continuity of CRP management and funding provided by IAEA.

## 9. Logical Framework

Narrative Summary	Verifiable Indicators	Means of Verification	Important Assumptions
<p><b>Overall objective</b></p> <p>To enhance the productivity and sustainability of farming systems through a better understanding of the principles and practice of conservation agriculture</p>	N/A	N/A	N/A
<p><b>Specific objective</b></p> <p>To quantify the individual and interactive effects of conservation tillage practices, residue management, crop rotations, nutrient and water inputs to increase soil organic matter, resource use efficiency, agricultural productivity and environmental quality</p>	<p>Individual and interactive effects of key components of conservation agriculture on soil organic matter stocks, resource use efficiency, agricultural productivity and environmental quality investigated</p>	<p>Crop yield data; data on resource use efficiency; data on soil organic matter; data on environmental quality</p>	<p>Support from NARS; close coordination provided between contract and agreement holders and the Agency; appropriate technical and managerial support provided by the Project Officer; adequate funding available; experimental protocols agreed at first RCM</p>

Narrative Summary	Verifiable Indicators	Means of Verification	Important Assumptions
<b>Outputs</b>			
1. Data on carbon, water and nutrient dynamics under conservation agriculture in diverse agroecosystems	Comprehensive and verifiable data sets from a range of agroecosystems.	Annual reports	Appropriate experimental design and sampling strategies. Effective research teams. Sufficient human, institutional and financial resources. Favorable climatic conditions.
2. Means to extrapolate experimental findings across and between regions.	Modelled outputs. Decision support tools.	Models used to extend results beyond the experimental areas	Modelling expertise available
3. Enhanced capacity of NARS to conduct integrated soil, water and nutrient management studies with the aid of nuclear and related techniques.	Contract holders are trained and use nuclear and related techniques in their research.	Successful completion of training workshop at first RCM. Annual progress reports. Publications. New project initiatives formulated.	Contract holders receive sufficient training. Equipment and analytical facilities available in institution. Scientists in CRP remain active in research and obtain competitive research grants.
4 Research findings communicated to the wider community	Research results disseminated through publication of TECDOC, guidelines, scientific papers, conference and workshop presentations.	Citations in abstracting journals. Demand for publications. Website visits.	Contract holders write manuscripts; project officer coordinates publications.

Narrative Summary	Verifiable Indicators	Means of Verification	Important Assumptions
<p><b>Activities</b></p> <p>1. Consultants' Meeting (CM) formulates CRP</p> <p>2. Project Officer and Consultants identify key institutions and personnel to participate in CRP</p> <p>3. Research network formed through research contracts and agreements</p> <p>4. 1<sup>st</sup> research co-ordination meeting finalizes workplan and experimental protocols</p> <p>5. Research specified in work plan conducted according to timeframe</p> <p>6. 2<sup>nd</sup> research co-ordination meeting reviews progress and plans research</p> <p>7. Mid-term review of CRP conducted</p> <p>8. 3<sup>rd</sup> research co-ordination meeting reviews progress and plans research</p> <p>9. 4<sup>th</sup> research co-ordination meeting reviews CRP activities and formulates conclusions and recommendations</p> <p>10. Publications</p>	<p>Consultants' Meeting held and project document prepared by September 2003</p> <p>Project Officer gathers information and contacts prospective clients</p> <p>Research proposals and agreements received by July 2004 and evaluated by September 2004.</p> <p>By April 2005 RCM and workshop held. Workplans and experimental protocols developed and agreed.</p> <p>Progress reports submitted on time</p> <p>By Oct 2006 RCM held. Annual progress reports submitted on time</p> <p>By Dec. 2006, review document submitted to PCC</p> <p>By April 2008 RCM held. Annual progress reports submitted on time</p> <p>By Oct 2009 final RCM held. Final reports and manuscripts submitted on time</p> <p>By Oct 2010 all manuscripts received, edited and peer-reviewed where necessary</p>	<p>Report of Consultants' Meeting. Project document completed.</p> <p>Research contract proposals and agreements submitted</p> <p>Contracts and agreements awarded; CRP commences Jan.- Feb. 2005</p> <p>Report of RCM</p> <p>Individual annual reports</p> <p>Report of RCM</p> <p>Review document in prescribed format</p> <p>Report of RCM</p> <p>Final reports and manuscripts submitted. Report of final RCM</p> <p>TEDOC or special journal issue published.</p>	<p>Consultants available and actively participate in CM; PCC approves CRP</p> <p>Appropriate institutions and scientists notified of CRP</p> <p>PCC approves contracts; Scientists and funding available</p> <p>Scientists and funding available</p> <p>Scientists and funding adequate to conduct research</p> <p>Scientists submit reports and participate in RCM</p> <p>Project officer prepares document in timely manner</p> <p>Scientists submit reports and participate in RCM</p> <p>Scientists submit reports and participate in RCM</p> <p>Manuscripts of sufficient quality received. Funds available for editing and publication.</p>

## **10. Brief Summary for the Agency's Bulletin**

Conservation agriculture (CA) is a management system that maintains a continuous soil cover through surface retention of all crop residues, reduced or zero tillage, and the use of cover or green manure crops in rotations. CA is practiced on a total of 72 Mha of cropland worldwide, with the proportions of total croplands under CA being 47.5 % in Latin America, 36.7 % in North America, 12.5 % in Australia and 3.3 % in the rest of the world. CA has potential application in all agroecological zones, and is expected to expand rapidly in Asia and more gradually into Africa and Europe as socio-economic conditions permit. Many positive benefits are claimed for CA including *inter alia* reduced soil erosion, improved soil fertility, better water relations, soil organic matter accumulation, reduced soil compaction, increased soil biodiversity, resilience to climate change and greenhouse gas mitigation, all of which interact in a complex way to increase agricultural productivity and system sustainability. However, there is a paucity of experimental data to support many of these claims. The overall objective of the CRP is to enhance the productivity and sustainability of farming systems through a better understanding of the principles and practice of conservation agriculture. More specifically, the individual and interactive effects of conservation tillage practices, residue management, crop rotations, nutrient and water inputs on soil organic matter stocks, resource use efficiency, agricultural productivity and environmental quality will be investigated. The project will be implemented in 2005 and preference will be given to scientists and institutions with experience in nuclear techniques and on-going research in conservation agriculture, so that the CRP can be fully integrated with existing experiments and available resources.