# CropSyst Simulations

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# Soil Carbon Sequestration

- **Growers are increasingly interested in participating in the emerging carbon trading market and managing their cropping systems to increase the potential for carbon sequestration in the soil.**
- **Cropping systems using direct seeding technology provide environmental services by protecting the soil surface from water and wind erosion, reducing the energy requirement for mechanized operations, and sustaining soil quality. The current expectation is that the technology will also enhance soil carbon sequestration.**

# Soil Carbon Sequestration

- Conditions leading to soil organic carbon (SOC) storage require evaluation, which cannot be easily accomplished via experimentation or direct observation.
- The use of computer simulation models has emerged as a necessary approach to address carbon sequestration in agriculture, with increasing acceptance as a reasonable degree of confidence in model capabilities becomes established.

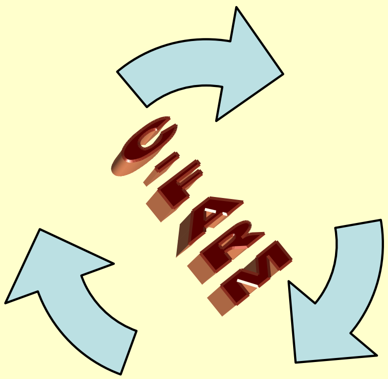
# Soil Carbon Sequestration

- **There is a strong demand for methods to compute and certify the soil carbon balance under different agricultural managements to support carbon credit markets**

- **The principles for modeling soil carbon and nitrogen cycling (CNC) were formulated during the last decades and compiled in simulation models (e.g. McGill et al., 1981; Parton et al., 1994; Jenkinson, 1990; Verberne et al., 1990). A good review of models is given by Shaffer et al (2001).**

# Soil Carbon Sequestration

- In this presentation, we will provide some insight into the carbon sub-models in two models that we have developed: CropSyst and C-FARM
- We then will utilize these models to gain some understanding of the effect of current soil organic matter (SOM) content, residue inputs, and tillage systems on the potential for carbon sequestration from dryland cropping systems in the US Pacific Northwest (PNW).



# Objectives

- Examine long-term effects of
  - Tillage
  - Rotation
  - Location
- On
  - Carbon sequestration
  - Greenhouse gas emissions

# Locations of scenarios

- Lind (250 mm)
- St. John (435 mm)
- Pullman (550 mm)
- Othello (irrigated)

# Rotations

**Lind**

WW-SF

**St. John**

WW-SW-SF

**Pullman**

WW-SW-SB

WW-SW-SP

**Othello**

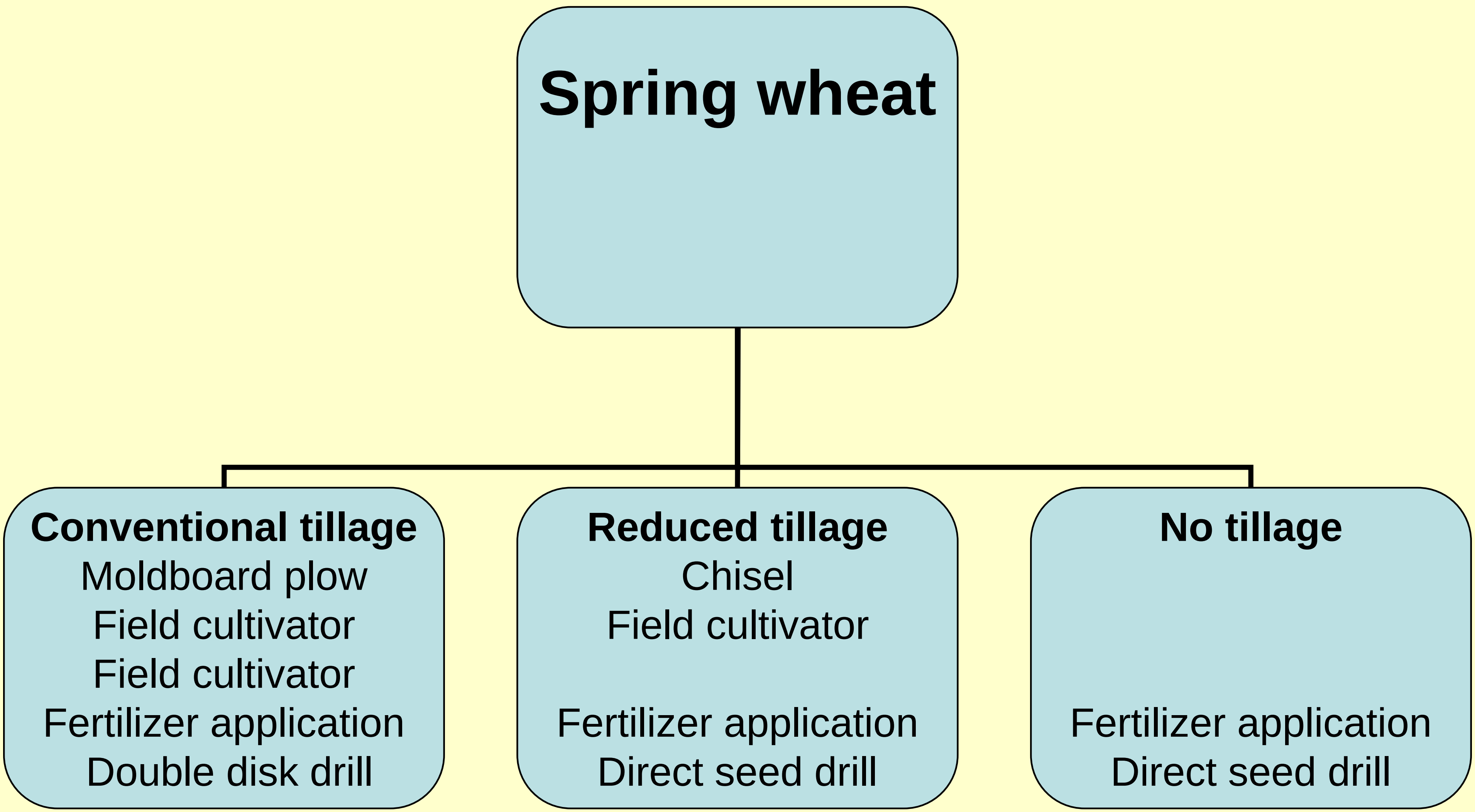
SC-SC-Potato-WW

SC-SC-Potato

# Tillage options

- Conventional (Representative)
- Reduced
- Minimum
- None

# Pullman tillage example

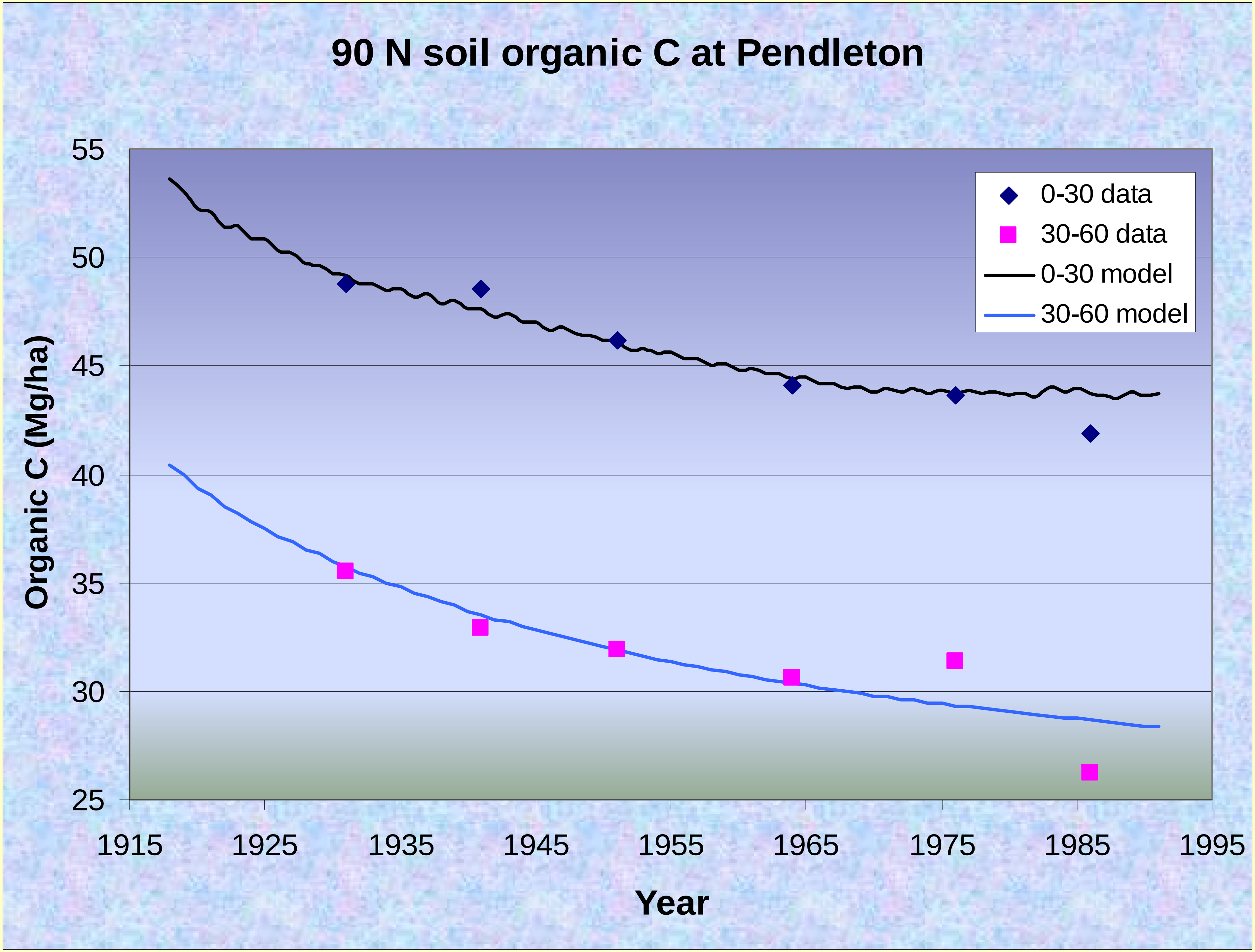


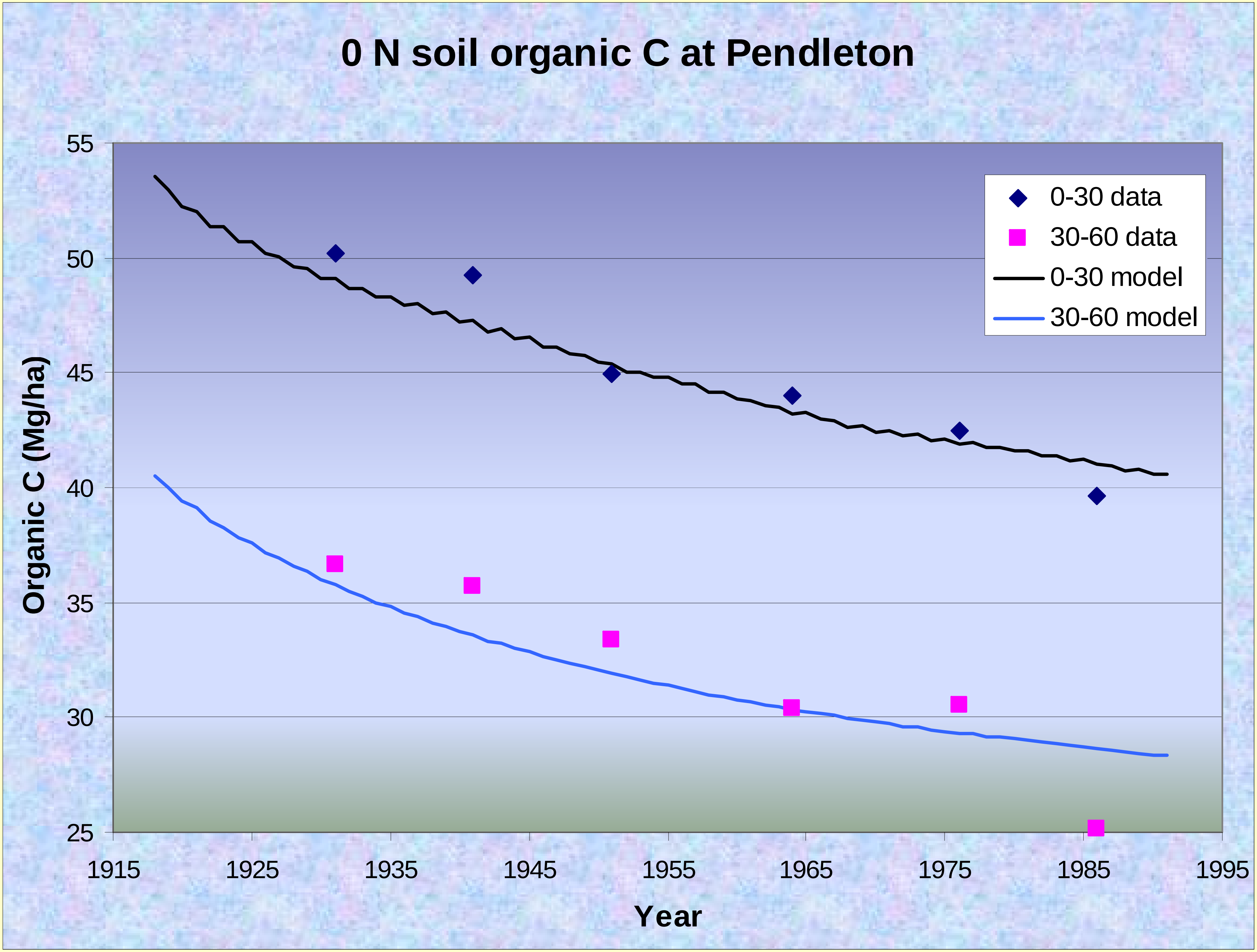
# What is CropSyst?


- CropSyst is a comprehensive, process-oriented, multi-year and multi-crop computer simulation model
- The model is designed to evaluate the productivity and environmental impact of cropping systems as affected by soil, weather, crop rotation, change of climatic conditions and atmospheric carbon dioxide concentration, and management decisions affecting the capture of solar radiation, water and nutrients (fertilization, irrigation, tillage, etc.)

# CropSyst calibration
## Pendleton historic data

- 1931 to 1991
- Low and high N application rates
- SOM 0-30 cm and 30-60 cm
- Crop yields (WW-SF)
- Conventional tillage


90 N soil organic C at Pendleton
Organic C (Mg/ha)
55
50
45
40
35
30
25
1915
1925
1935
1945
1955
1965
1975
1985
1995
Year
0-30 data
30-60 data
0-30 model
30-60 model


0 N soil organic C at Pendleton
Organic C (Mg/ha)
55
50
45
40
35
30
25
1915
1925
1935
1945
1955
1965
1975
1985
1995
Year
0-30 data
30-60 data
0-30 model
30-60 model

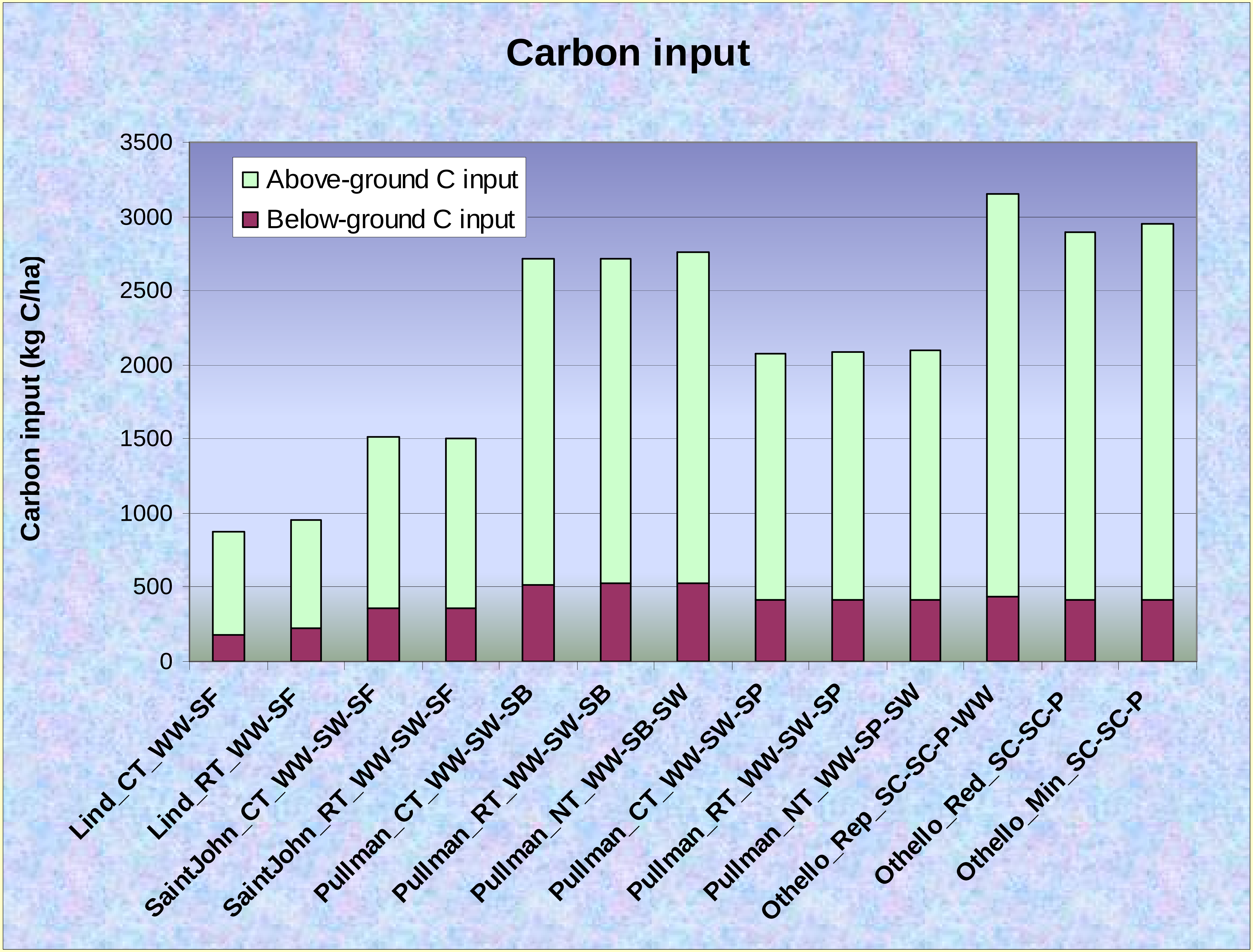
# Calibration of crops

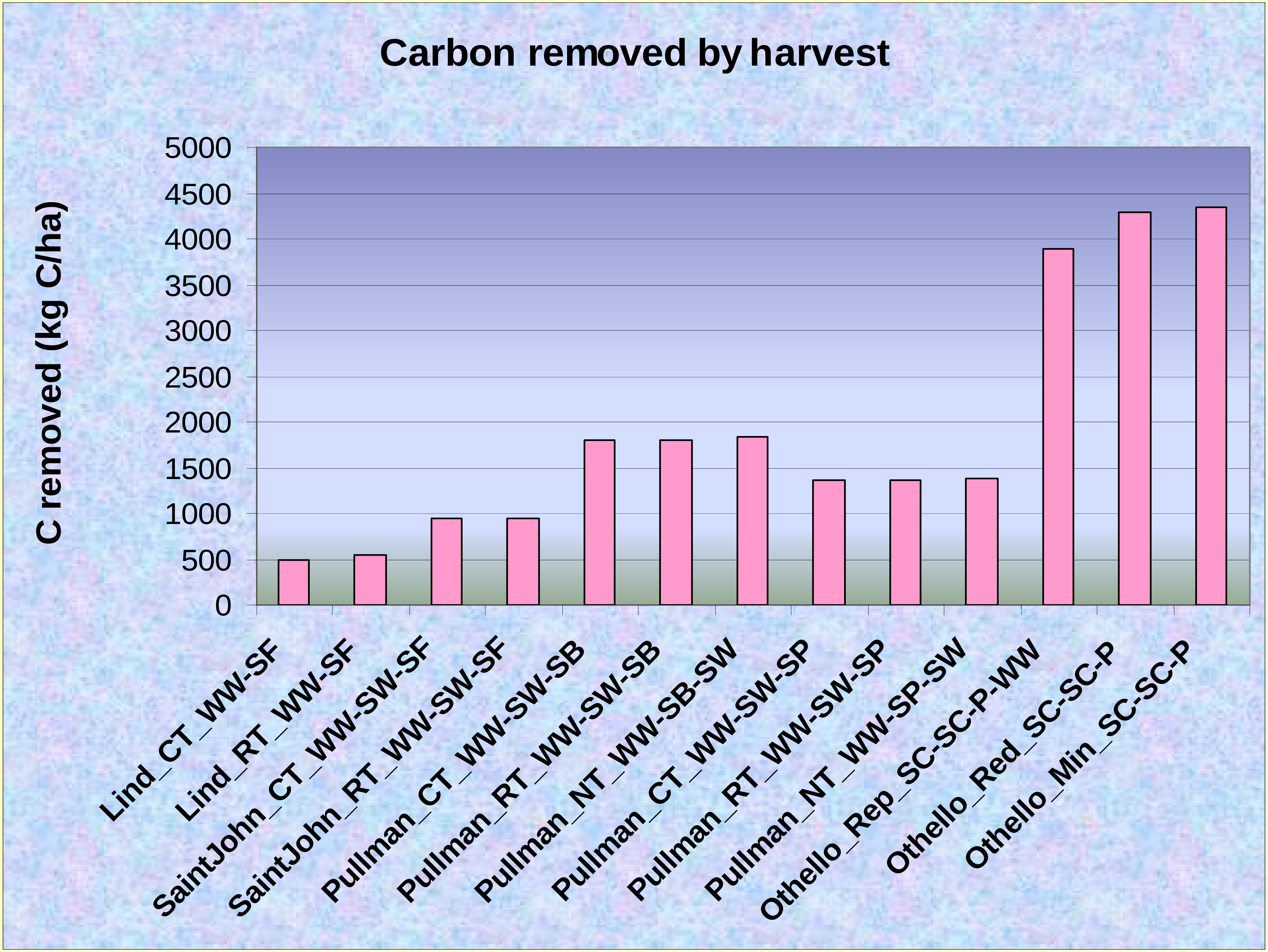
- Each location
- Each crop
- Conventional tillage
- Within 5% of historic yields
- 100-year simulation period

# Initial SOM % used for simulations

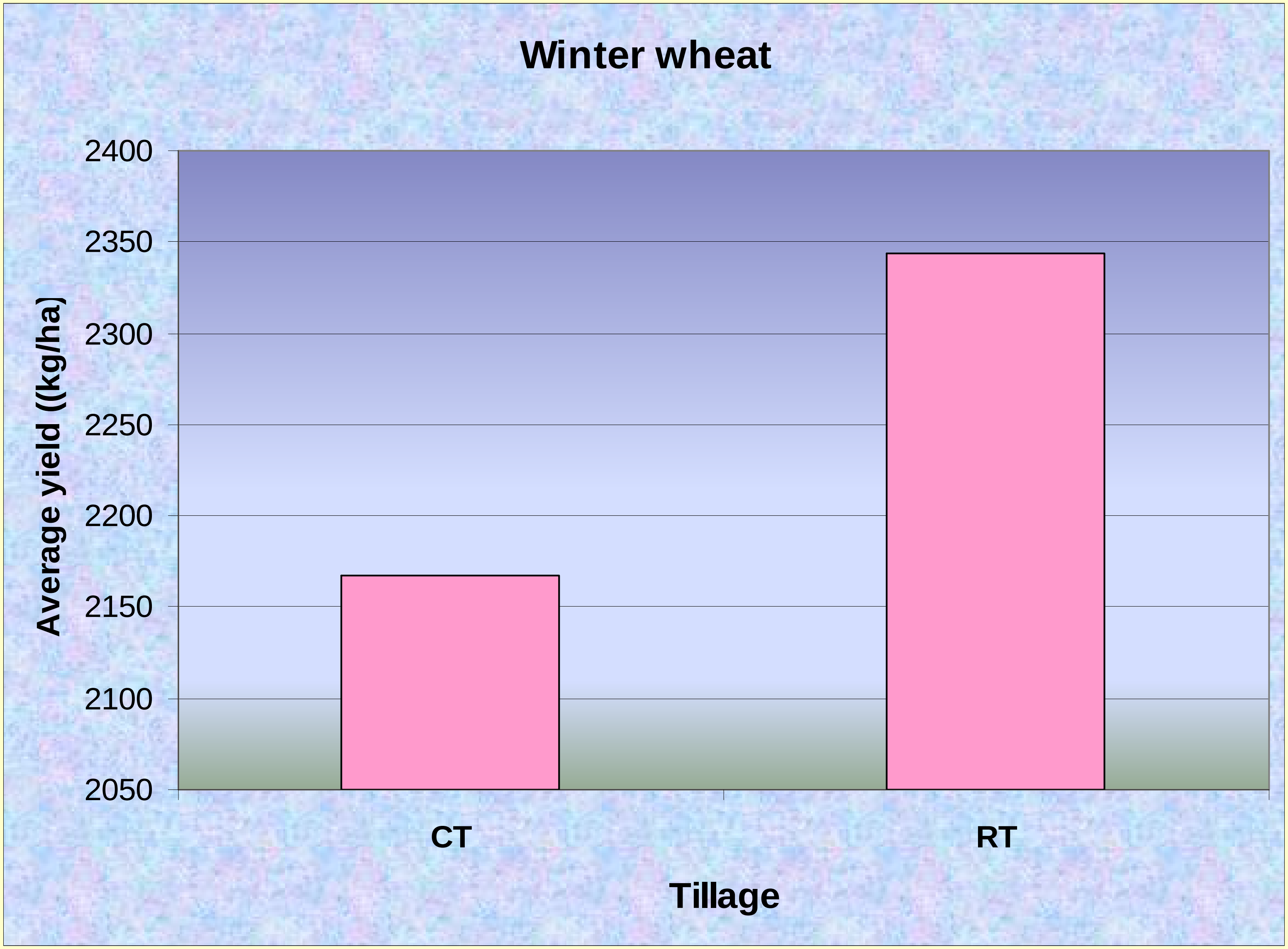
| Horizon | Lind | St John | Pullman | Othello |
|---|---|---|---|---|
| 1 | 0.8 | 1.46 | 2.38 | 0.64 |
| 2 | 0.8 | 1.46 | 2.38 | 0.64 |
| 3 | 0.8 | 1.46 | 2.38 | 0.28 |
| 4 | 0.45 | 0.82 | 1.34 | 0.28 |
| 5 | 0.45 | 0.82 | 1.34 | 0.21 |
| 6 | 0.45 | 0.82 | 1.34 | 0.21 |
| 7 | 0.18 | 0.33 | 0.54 | 0.1 |
| 8 | 0.18 | 0.33 | 0.54 | 0.03 |
| 9 | 0.05 | 0.08 | 0.14 | 0.03 |
| 10 | 0.05 | 0.08 | 0.14 | 0.03 |
| 11 | 0.05 | 0.08 | 0.14 | 0.03 |
| 12 | 0.05 | 0.08 | 0.14 | 0.03 |

# Results

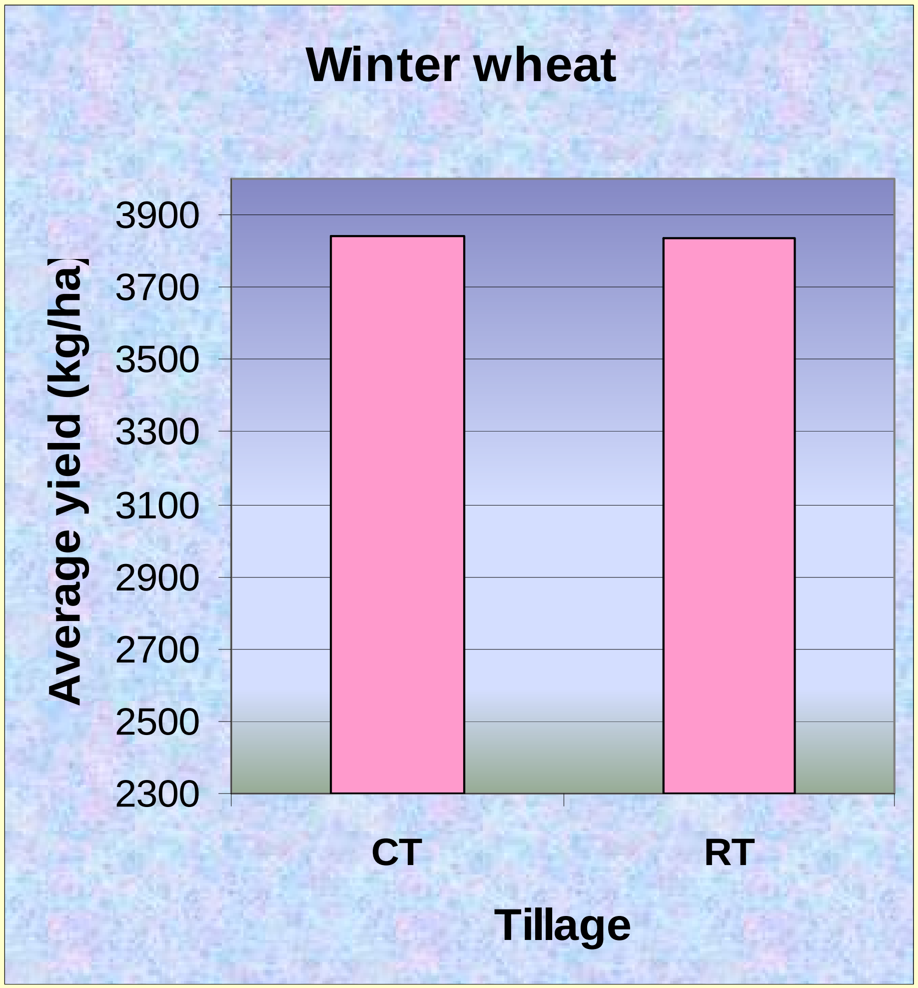

Carbon input
Above-ground C input
Below-ground C input
Carbon input (kg C/ha)
3500
3000
2500
2000
1500
1000
500
0
Lind_CT_WW-SF
Lind_RT_WW-SF
SaintJohn_CT_WW-SW-SF
SaintJohn_RT_WW-SW-SF
Pullman_CT_WW-SW-SB
Pullman_RT_WW-SW-SB
Pullman_NT_WW-SB-SW
Pullman_CT_WW-SW-SP
Pullman_RT_WW-SW-SP
Pullman_NT_WW-SP-SW
Othello_Rep_SC-SC-P-WW
Othello_Red_SC-SC-P
Othello_Min_SC-SC-P

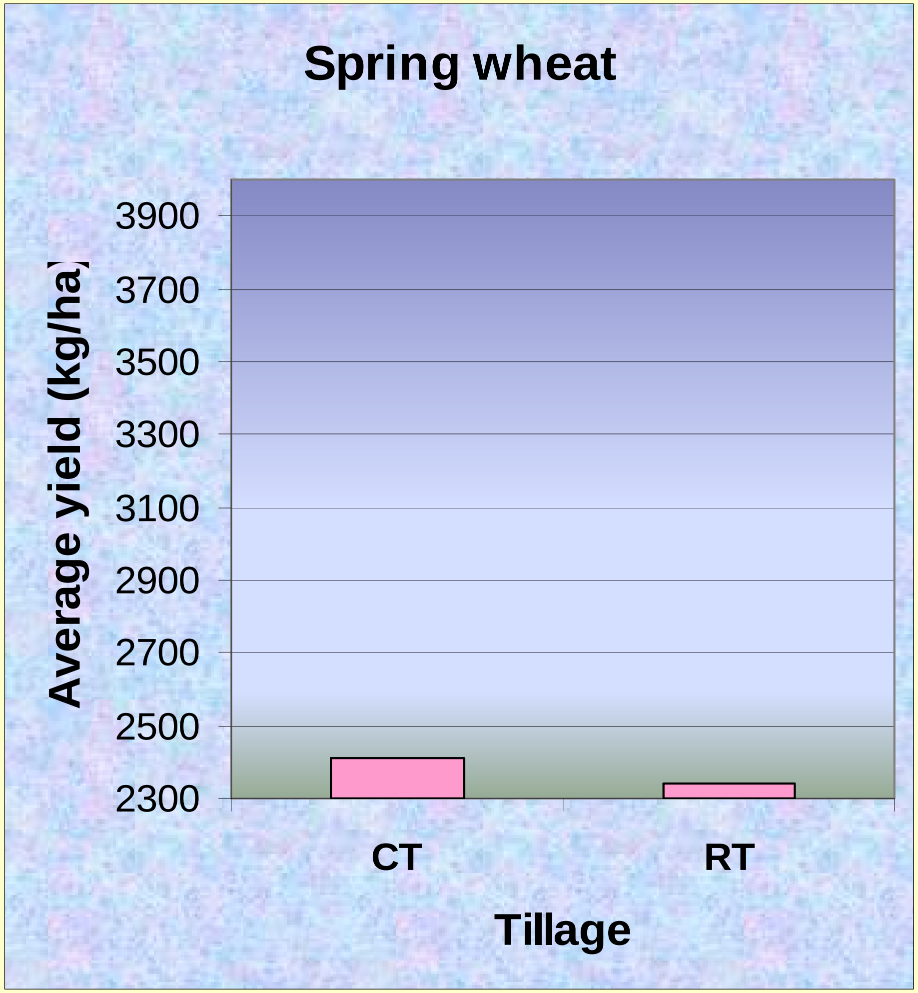

Carbon removed by harvest
C removed (kg C/ha)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Lind_CT_WW-SF
Lind_RT_WW-SF
SaintJohn_CT_WW-SW-SF
SaintJohn_RT_WW-SW-SF
Pullman_CT_WW-SW-SB
Pullman_RT_WW-SW-SB
Pullman_NT_WW-SB-SW
Pullman_CT_WW-SW-SP
Pullman_RT_WW-SW-SP
Pullman_NT_WW-SP-SW
Othello_Rep_SC-SC-P-WW
Othello_Red_SC-SC-P
Othello_Min_SC-SC-P

# Simulated Lind yields

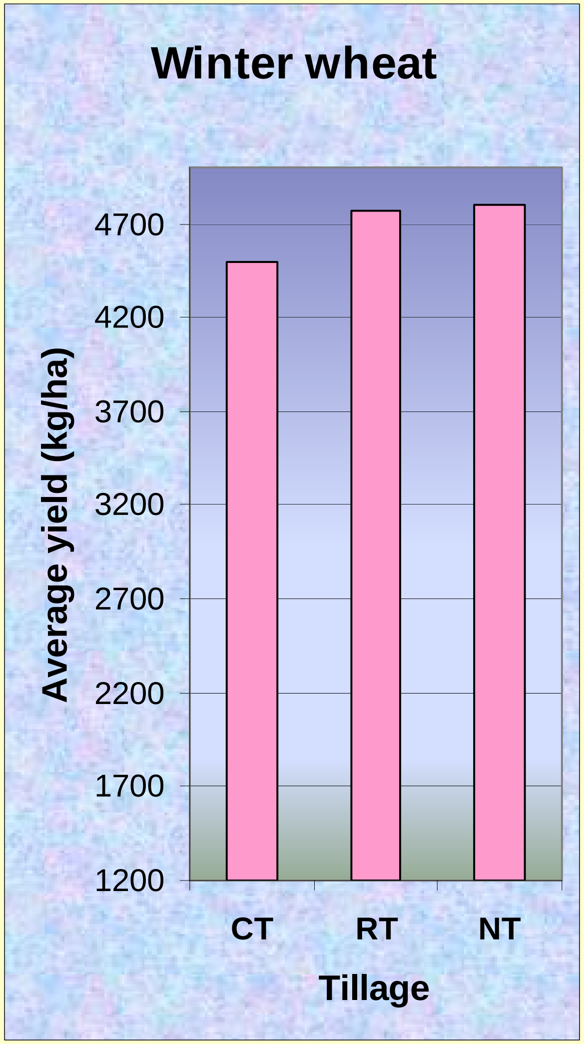


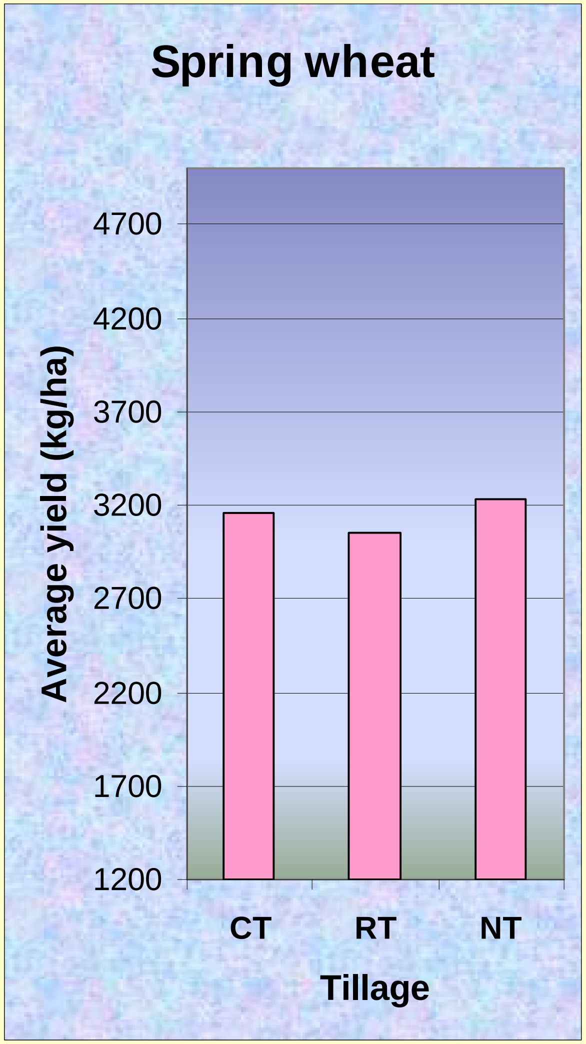
# Simulated St. John yields

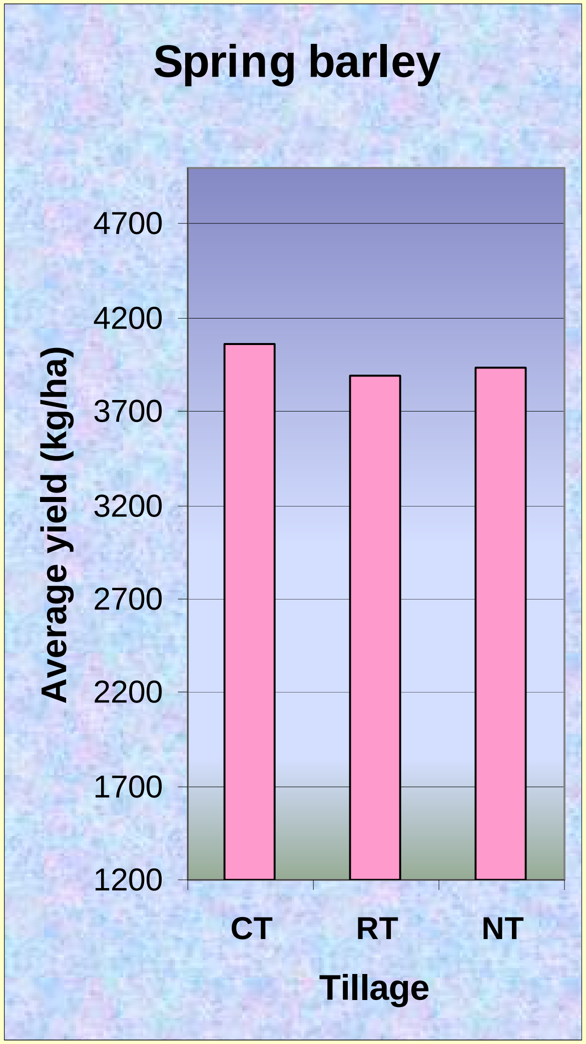


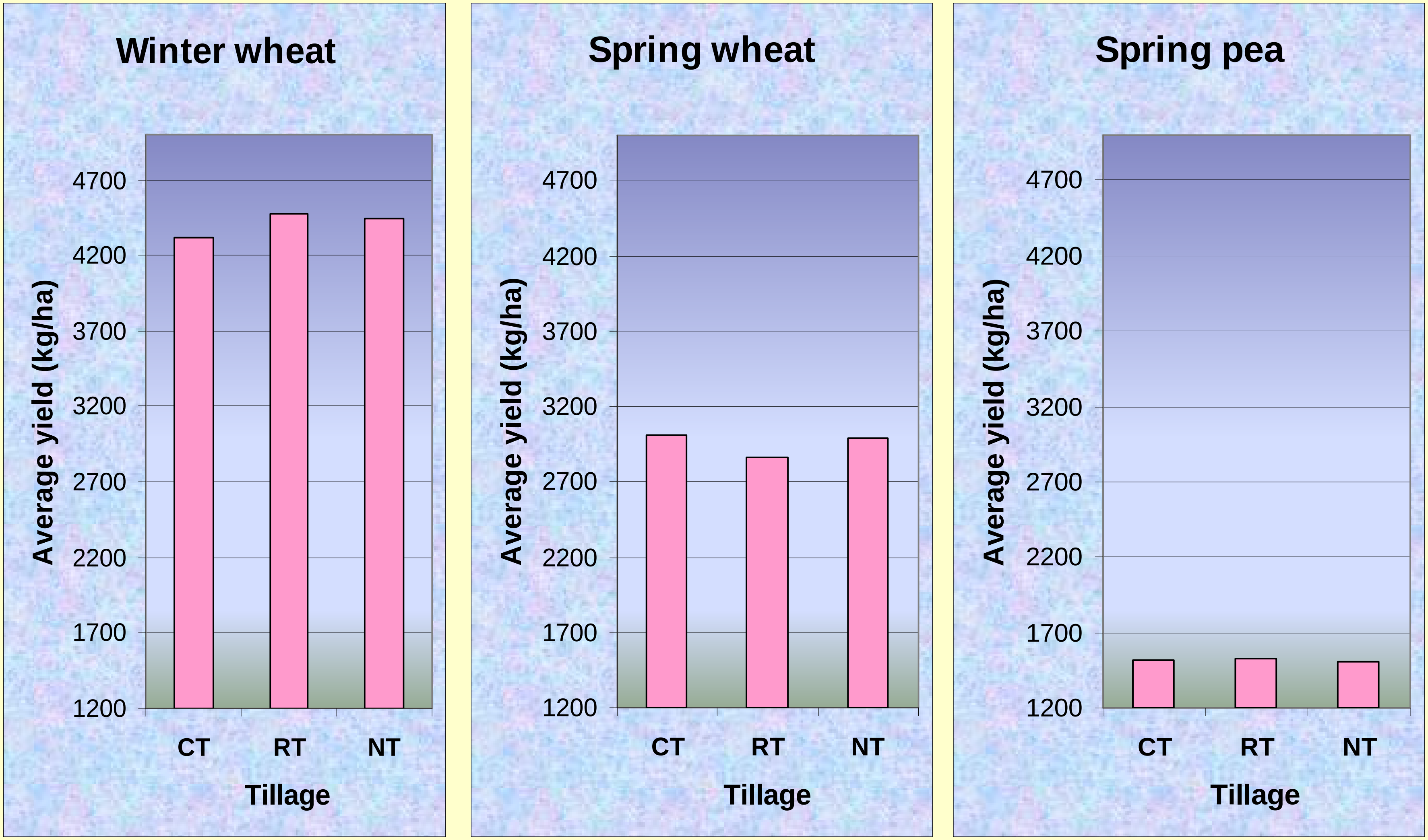
# Simulated Pullman yields with barley in rotation



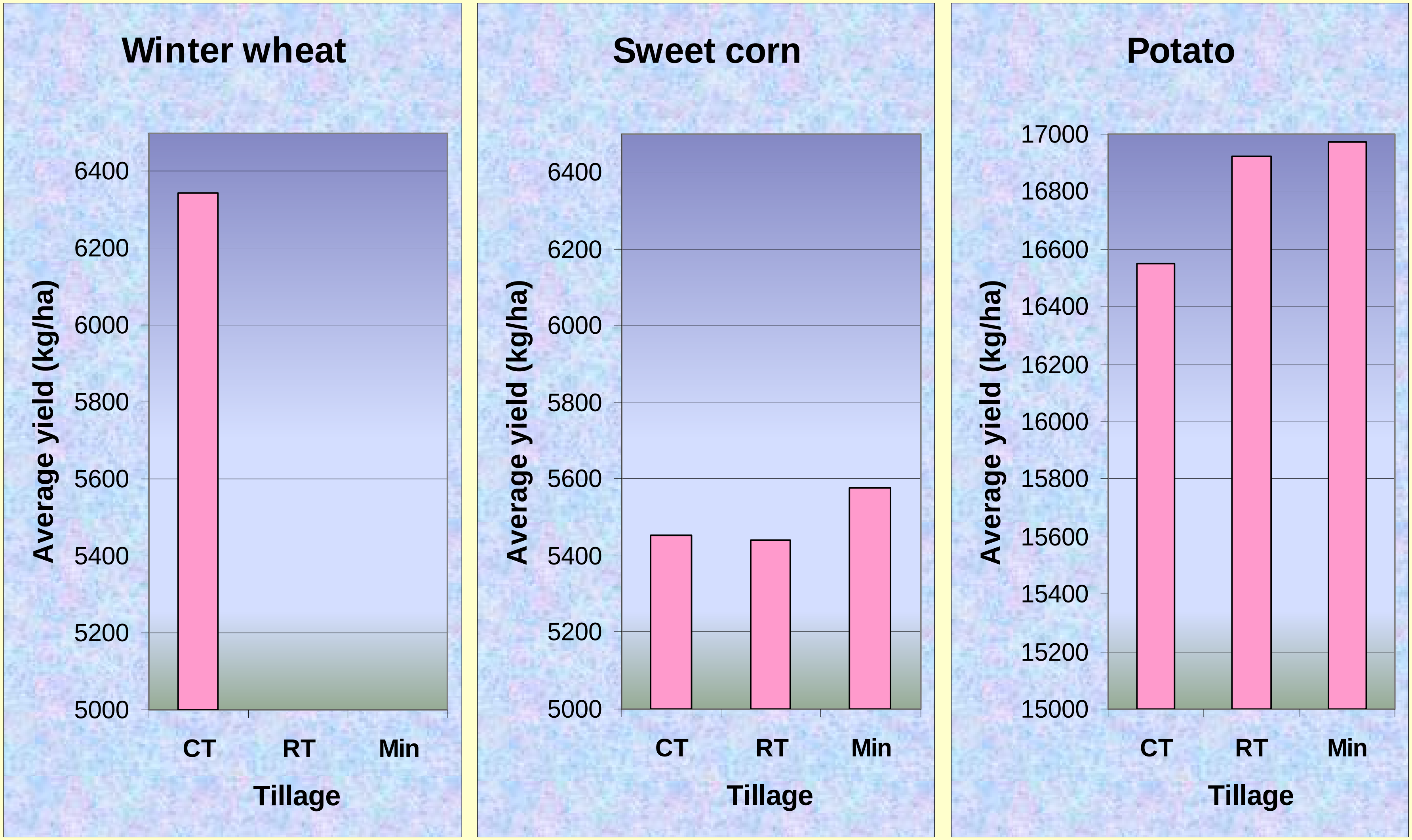



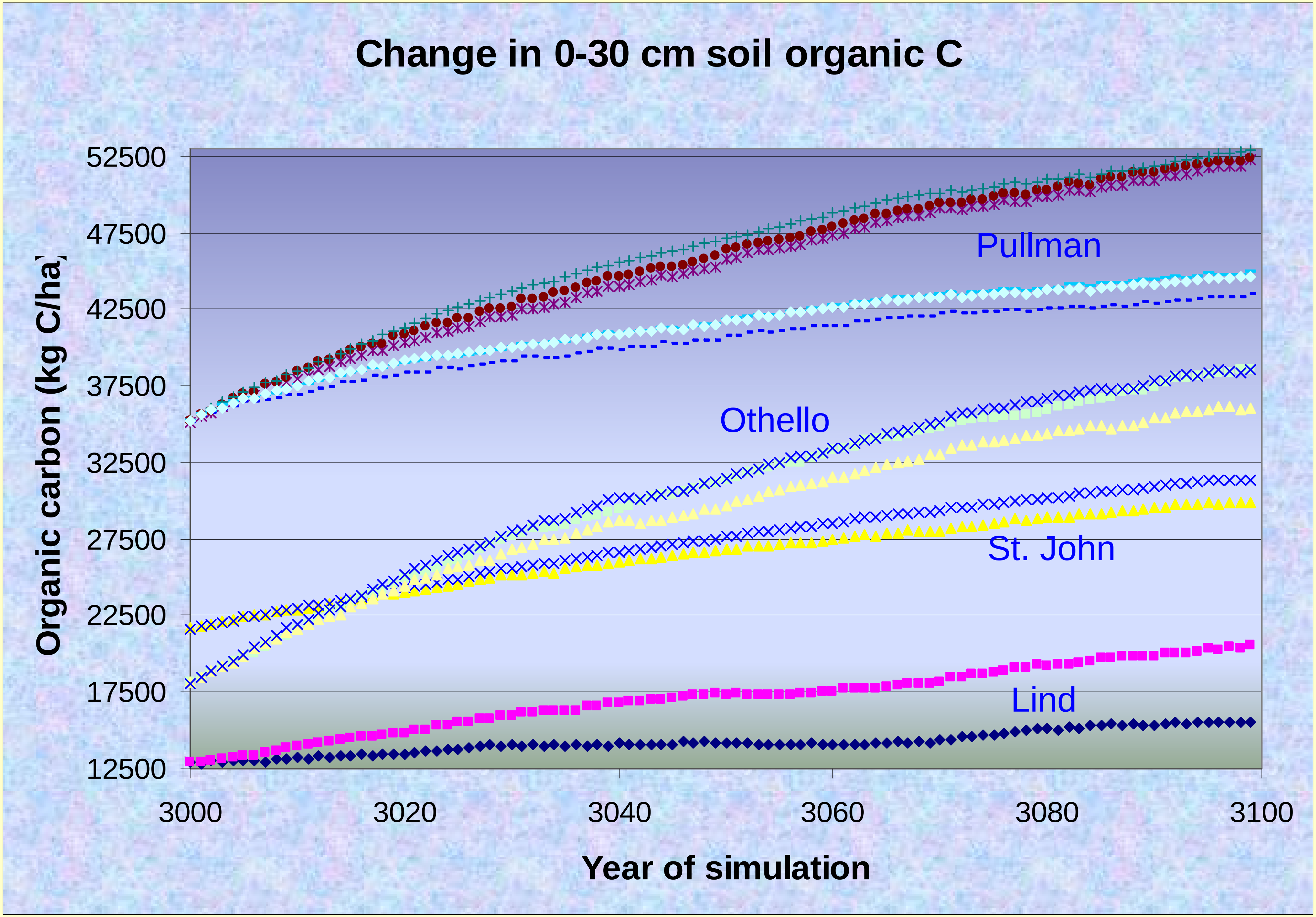



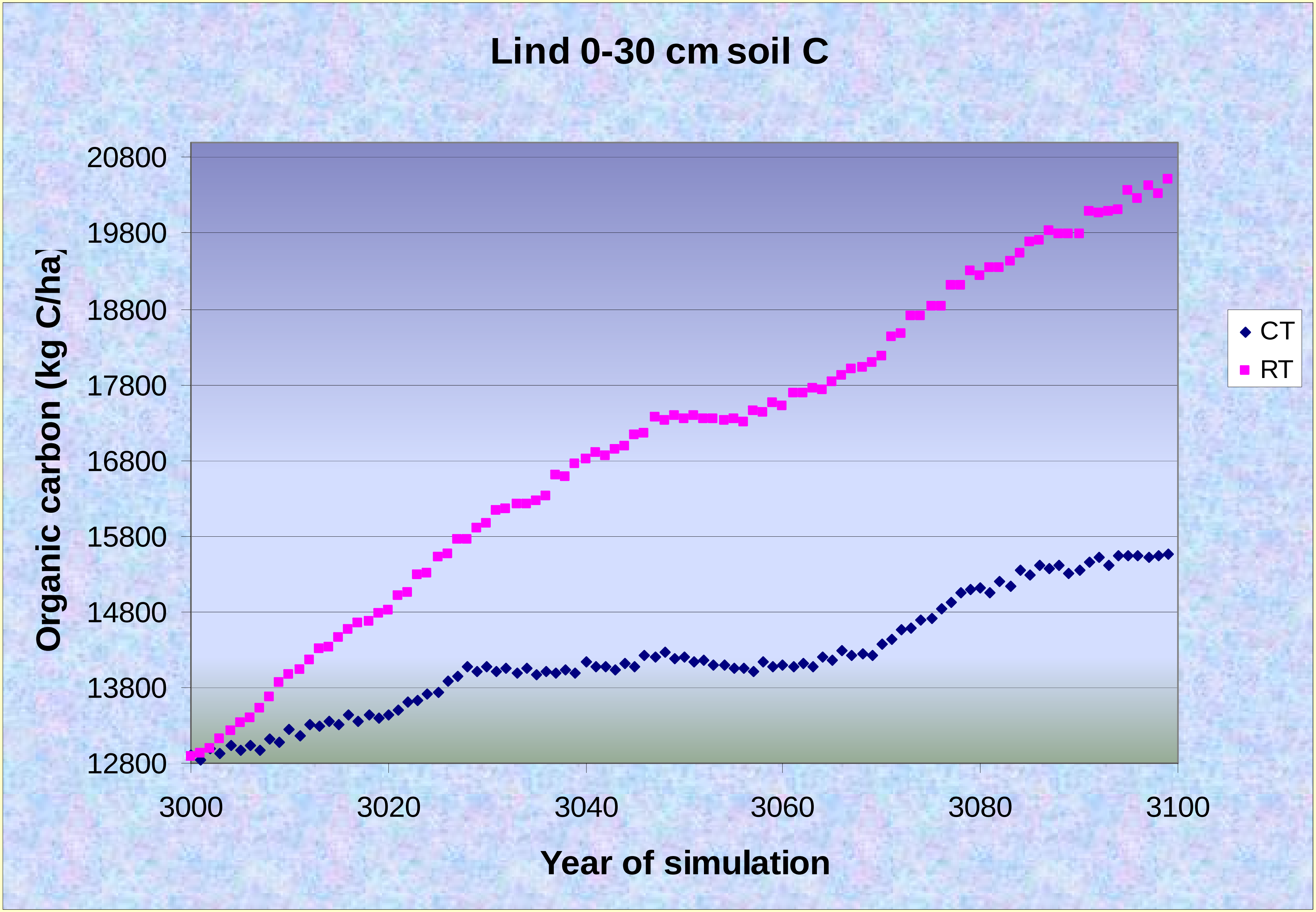
# Simulated Pullman yields with pea in rotation

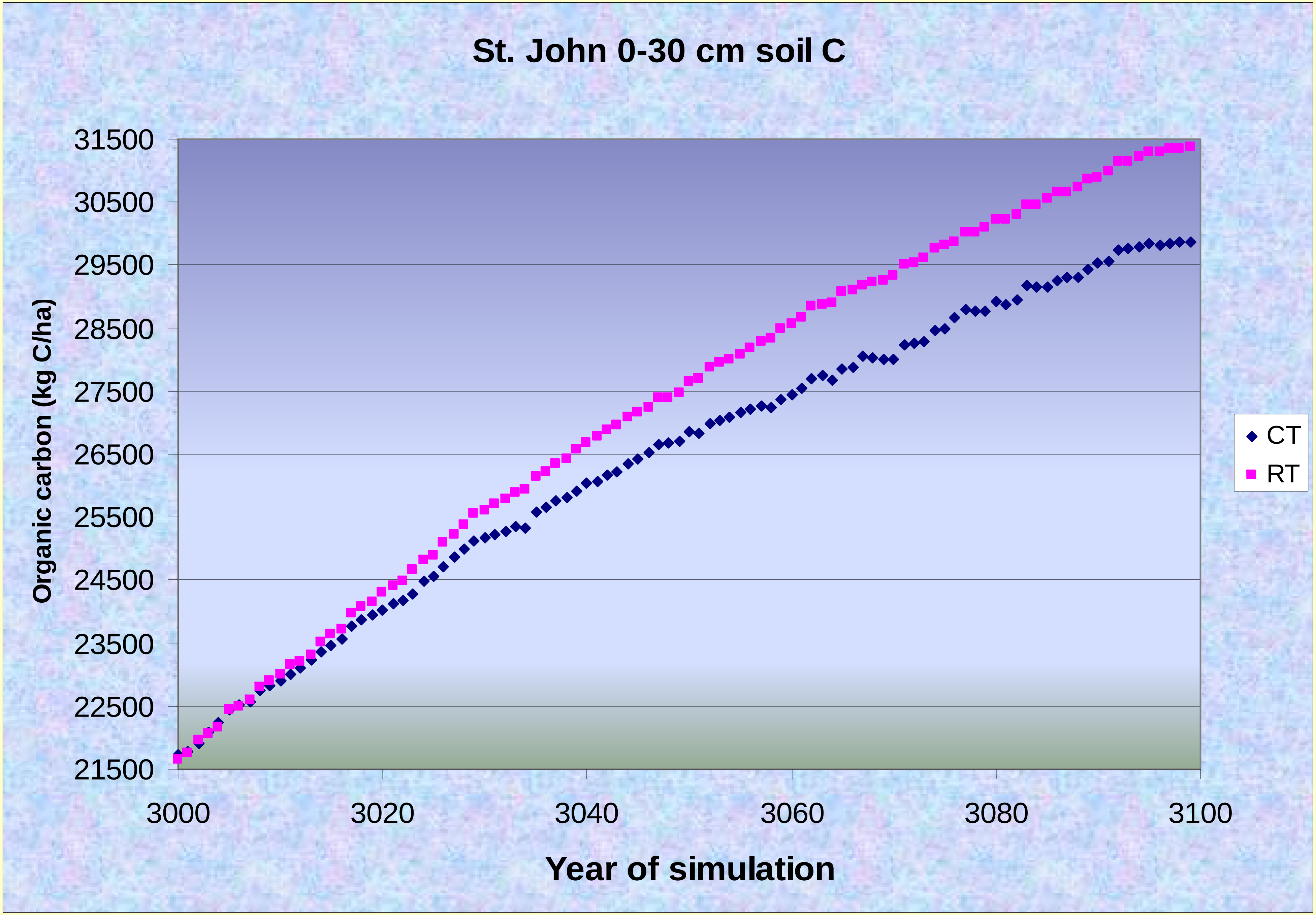


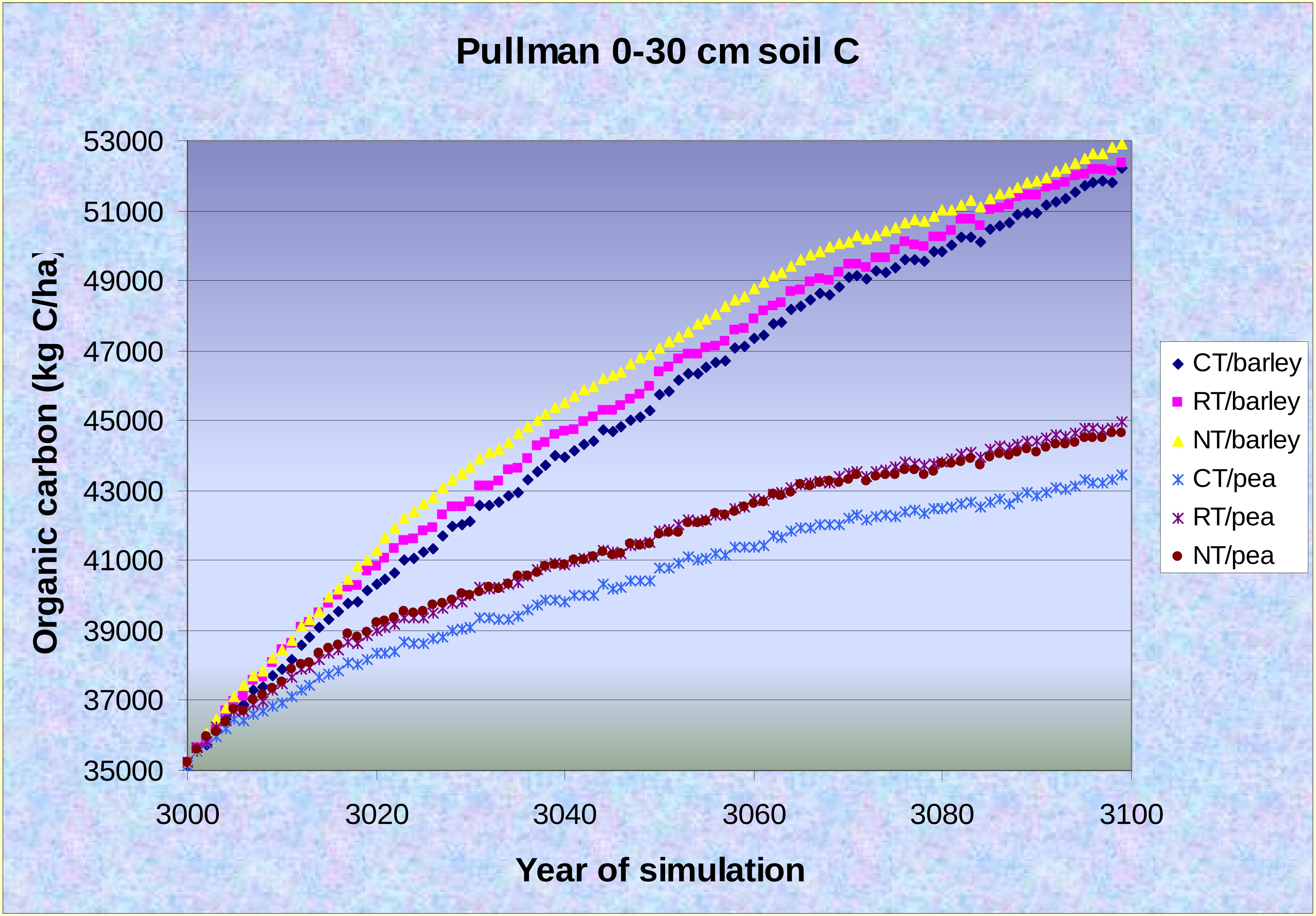
# Simulated Othello yields



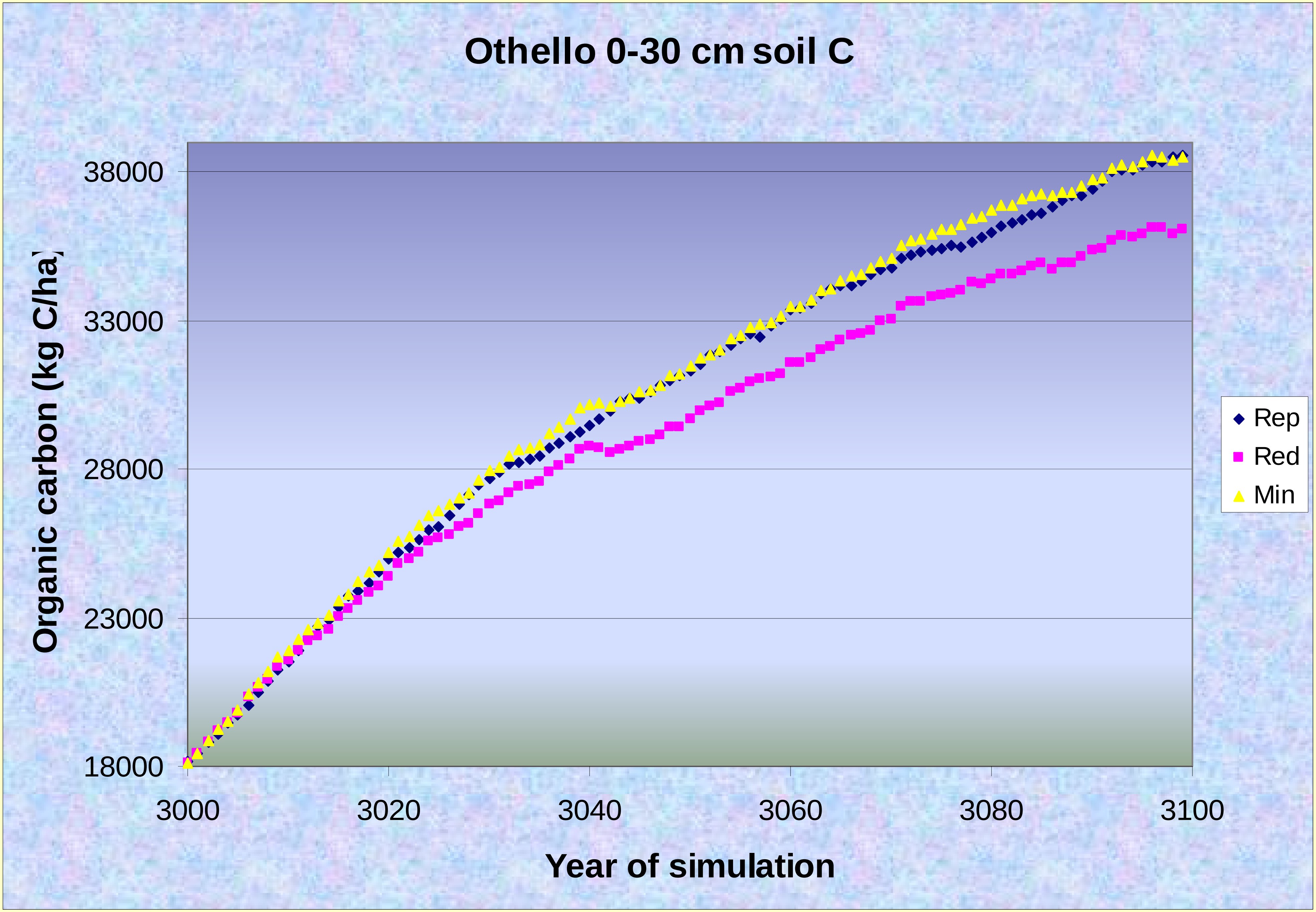

Change in 0-30 cm soil organic C
Organic carbon (kg C/ha)
52500
47500
42500
37500
32500
27500
22500
17500
12500
3000
3020
3040
3060
3080
3100
Year of simulation
Pullman
Othello
St. John
Lind

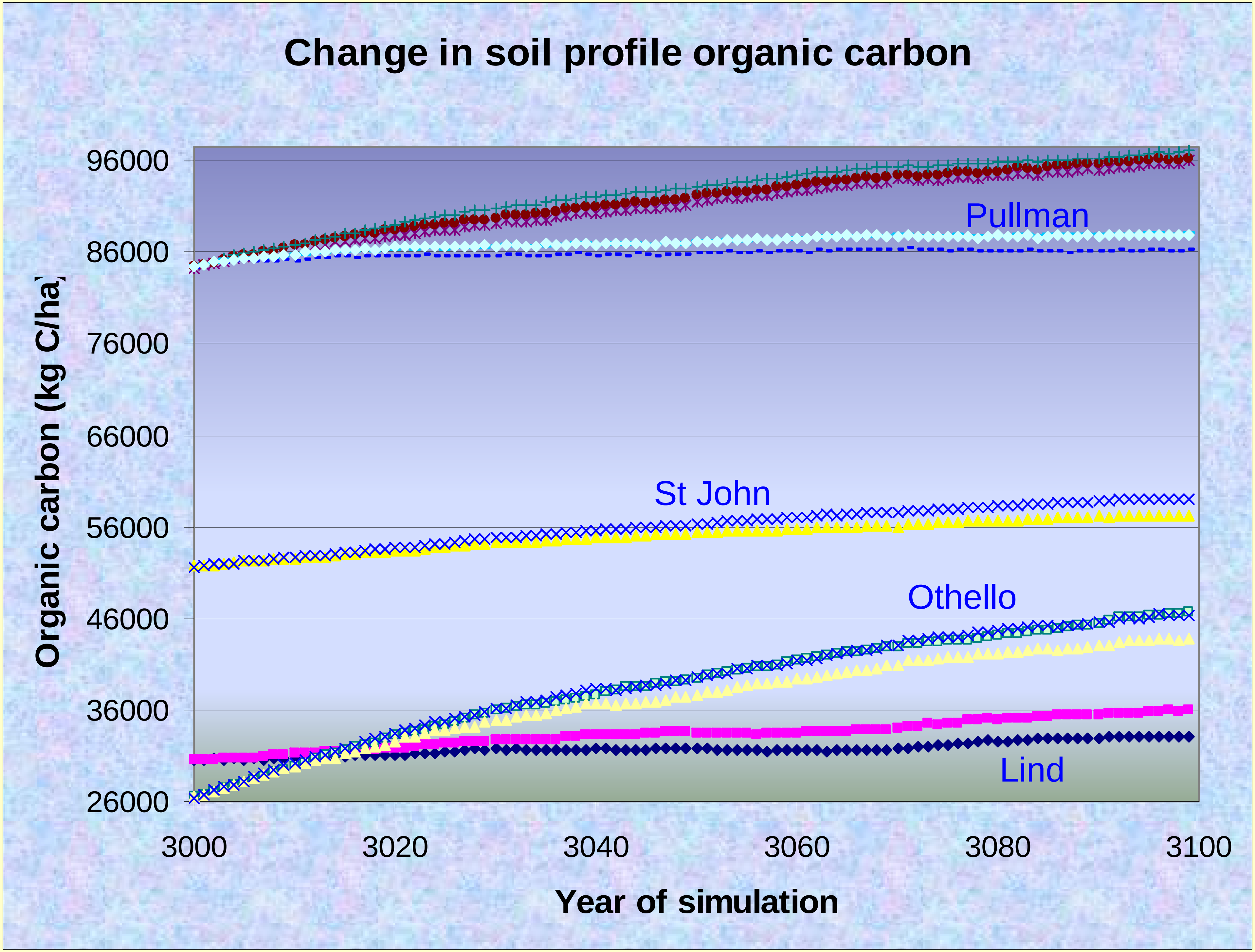

Lind 0-30 cm soil C
Organic carbon (kg C/ha)
20800
19800
18800
17800
16800
15800
14800
13800
12800
3000
3020
3040
3060
3080
3100
Year of simulation
CT
RT

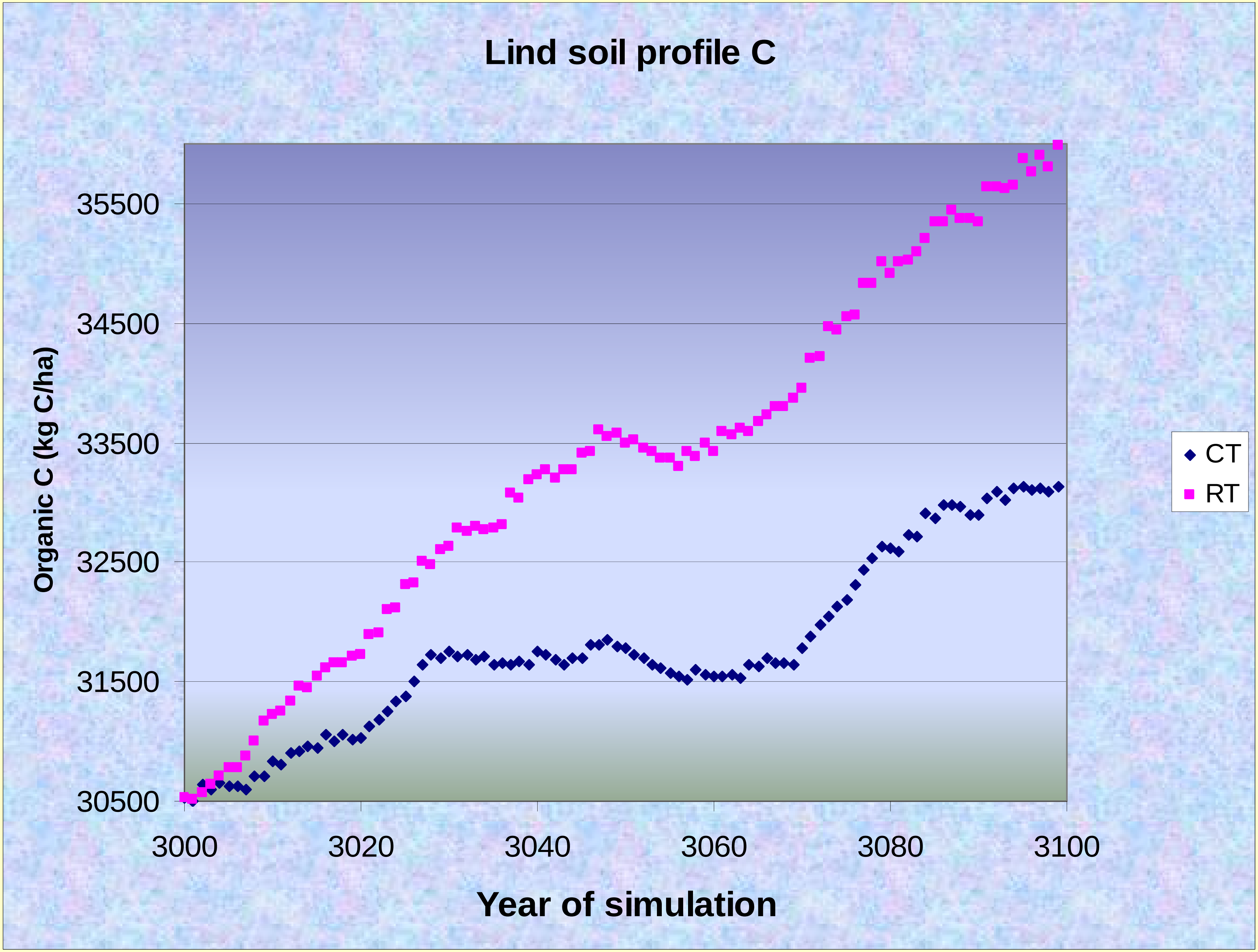

St. John 0-30 cm soil C
Organic carbon (kg C/ha)
31500
30500
29500
28500
27500
26500
25500
24500
23500
22500
21500
3000
3020
3040
3060
3080
3100
Year of simulation
CT
RT

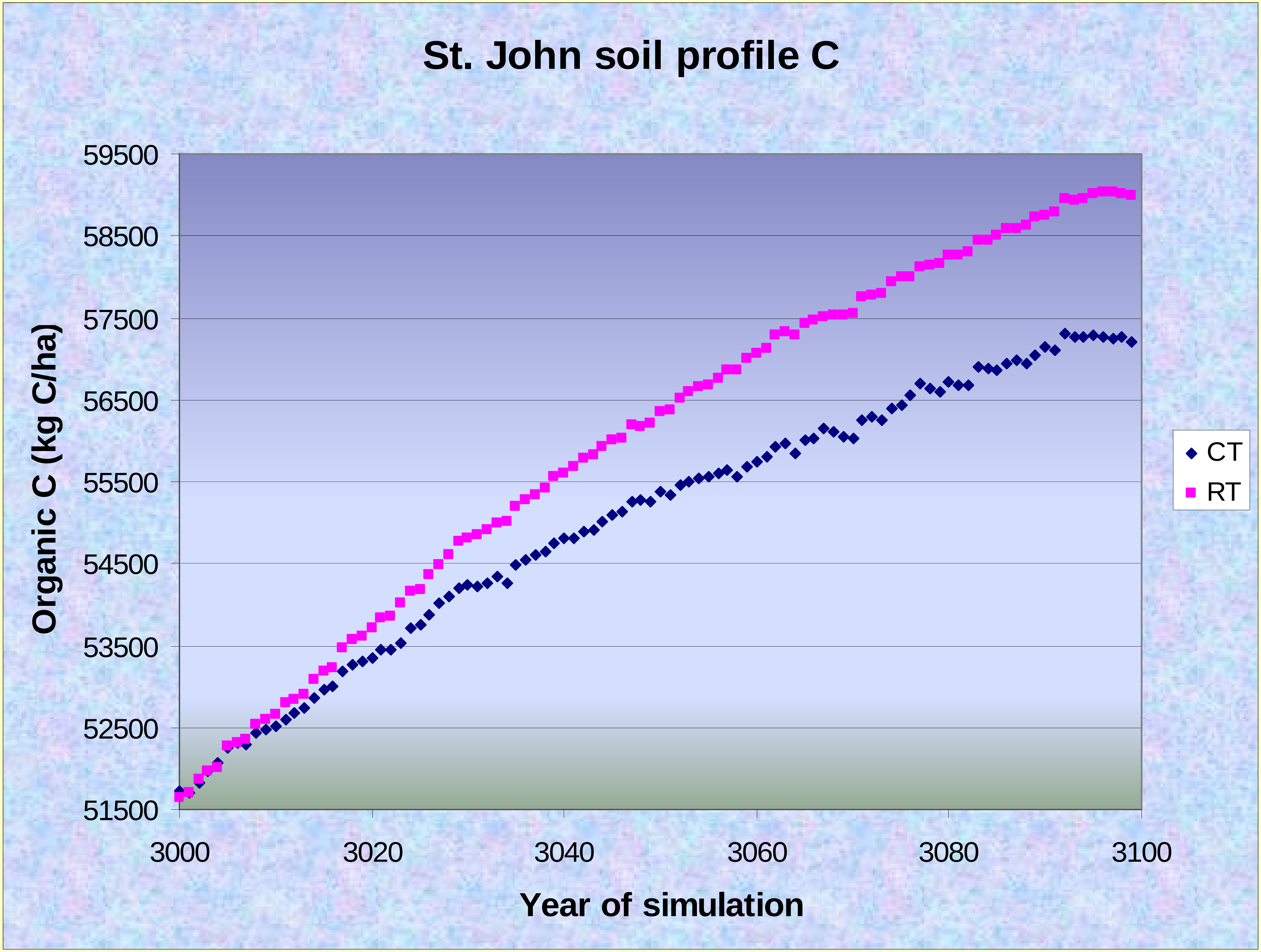


Pullman 0-30 cm soil C
Organic carbon (kg C/ha)
53000
51000
49000
47000
45000
43000
41000
39000
37000
35000
3000
3020
3040
3060
3080
3100
Year of simulation
CT/barley
RT/barley
NT/barley
CT/pea
RT/pea
NT/pea

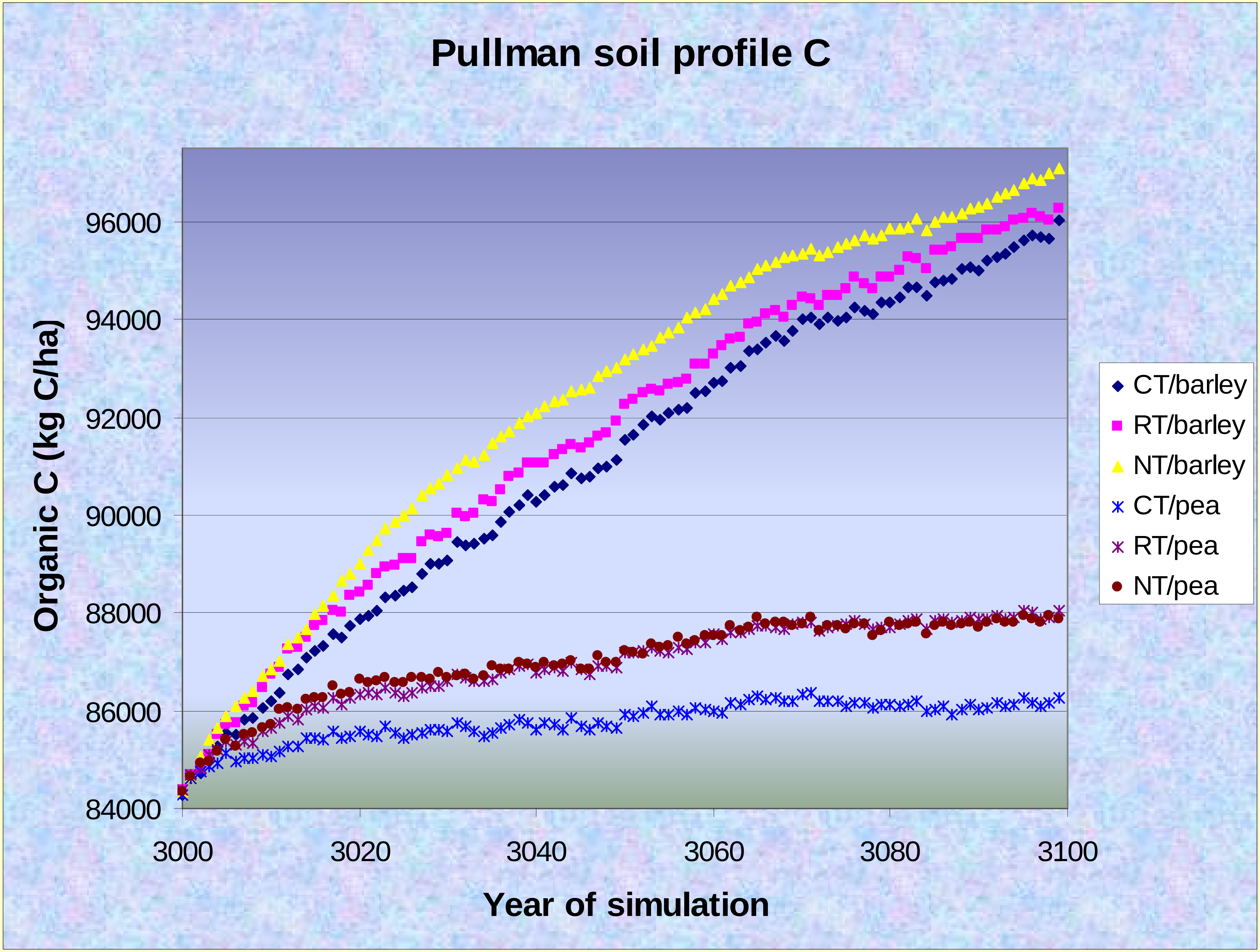

Othello 0-30 cm soil C
Organic carbon (kg C/ha)
38000
33000
28000
23000
18000
3000
3020
3040
3060
3080
3100
Year of simulation
Rep
Red
Min

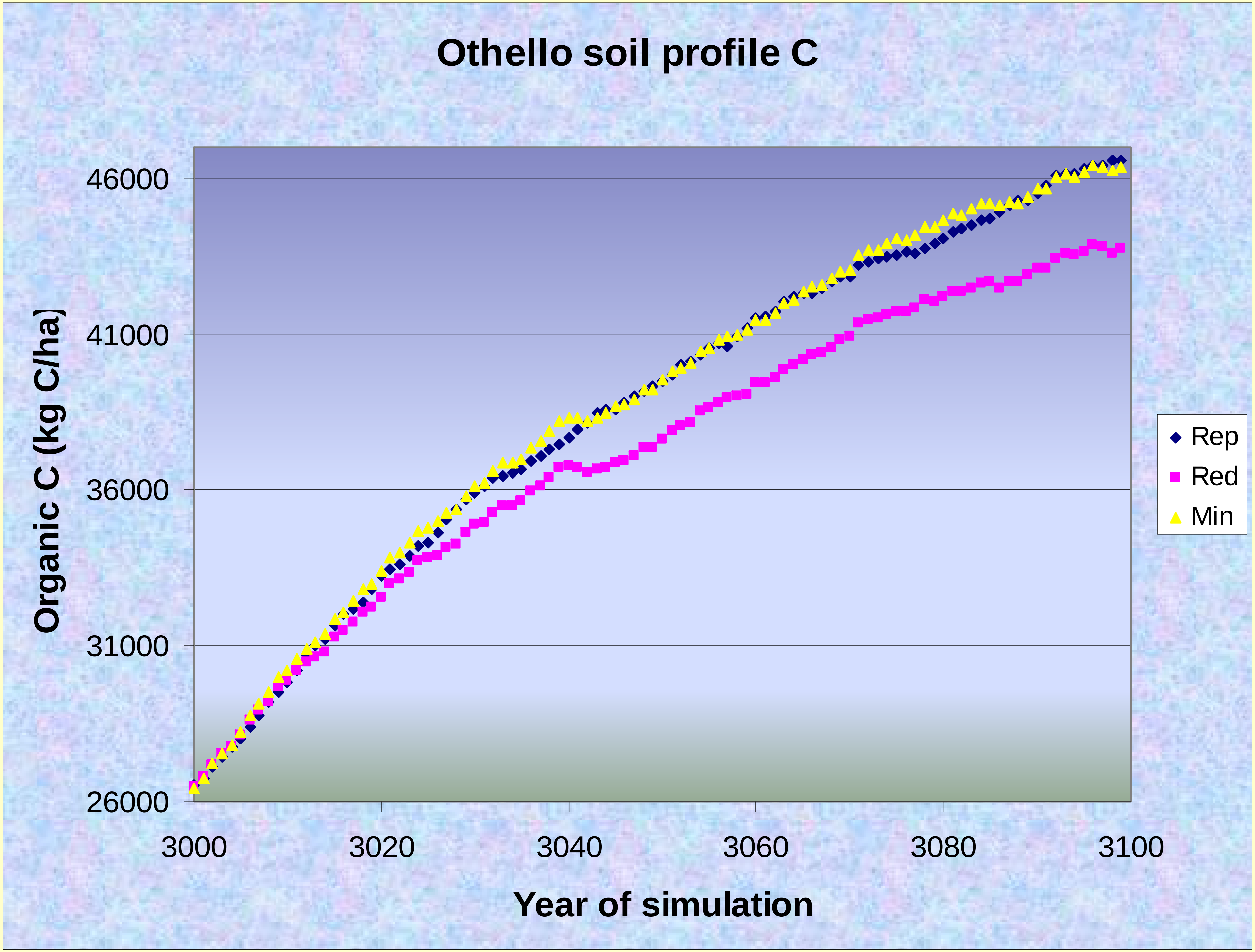

Change in soil profile organic carbon
Organic carbon (kg C/ha)
96000
86000
76000
66000
56000
46000
36000
26000
3000
3020
3040
3060
3080
3100
Year of simulation
Pullman
St John
Othello
Lind

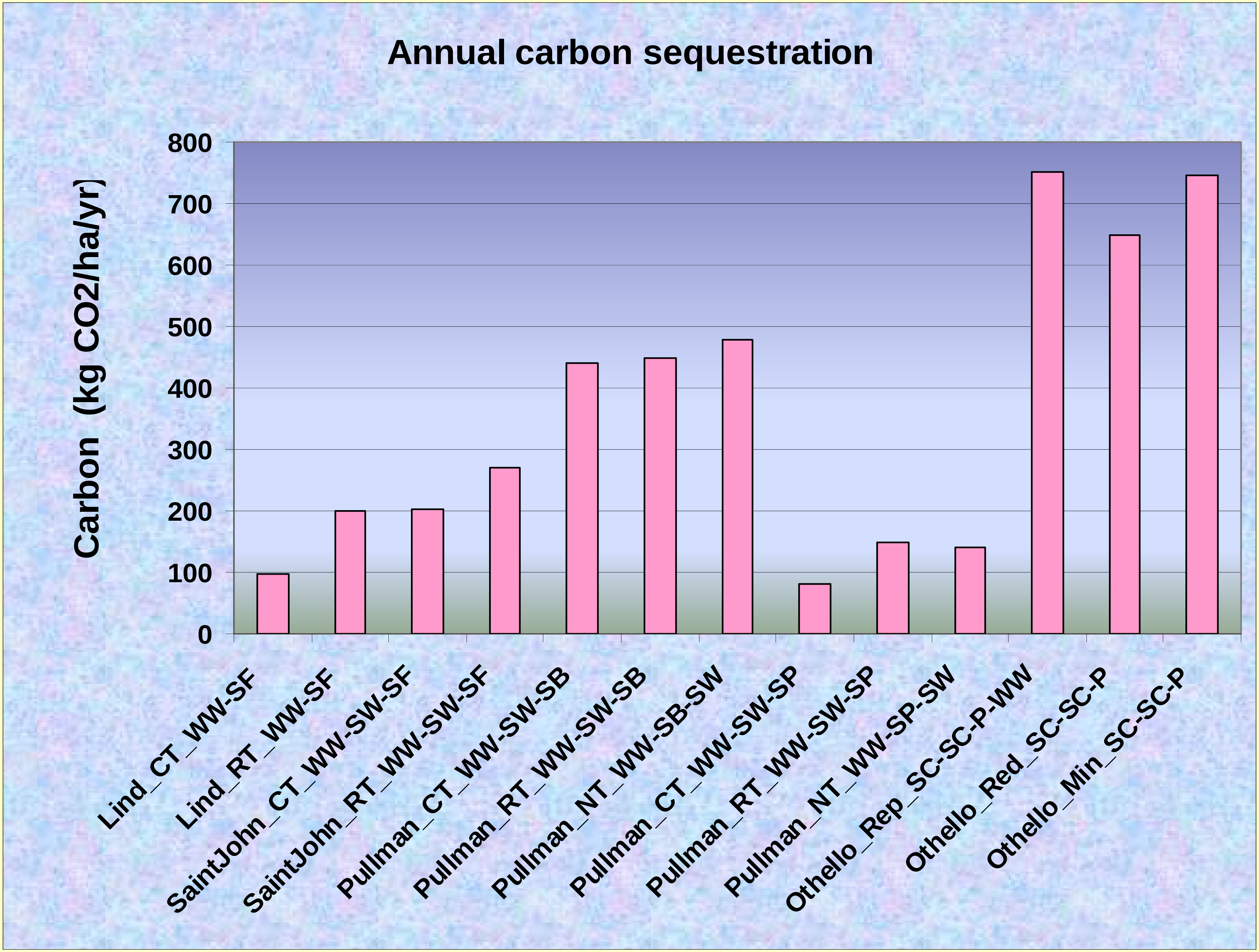

Lind soil profile C
Organic C (kg C/ha)
35500
34500
33500
32500
31500
30500
3000
3020
3040
3060
3080
3100
Year of simulation
CT
RT



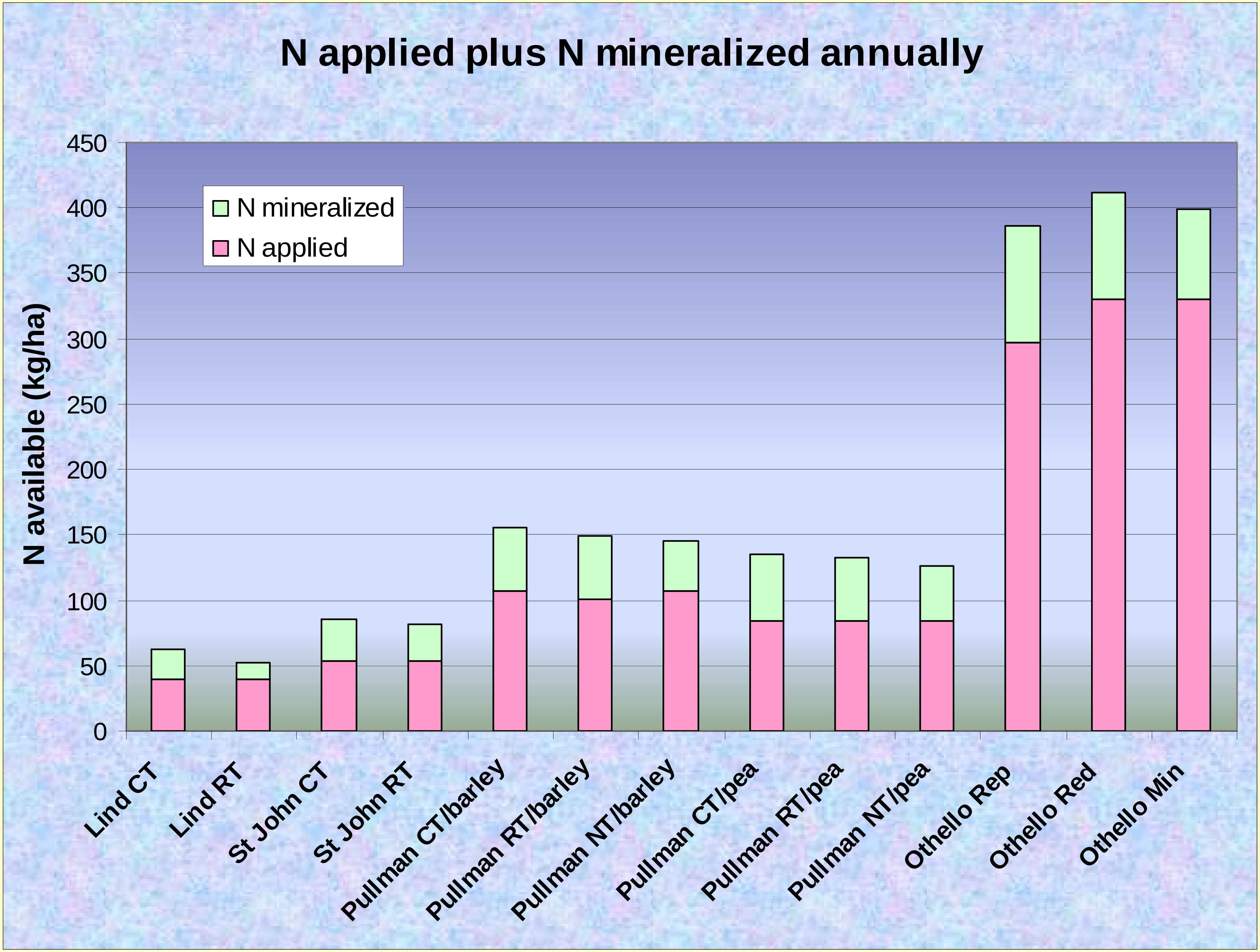
St. John soil profile C
Organic C (kg C/ha)
59500
58500
57500
56500
55500
54500
53500
52500
51500
3000
3020
3040
3060
3080
3100
Year of simulation
CT
RT


Pullman soil profile C
Organic C (kg C/ha)
84000
86000
88000
90000
92000
94000
96000
3000
3020
3040
3060
3080
3100
Year of simulation
CT/barley
RT/barley
NT/barley
CT/pea
RT/pea
NT/pea

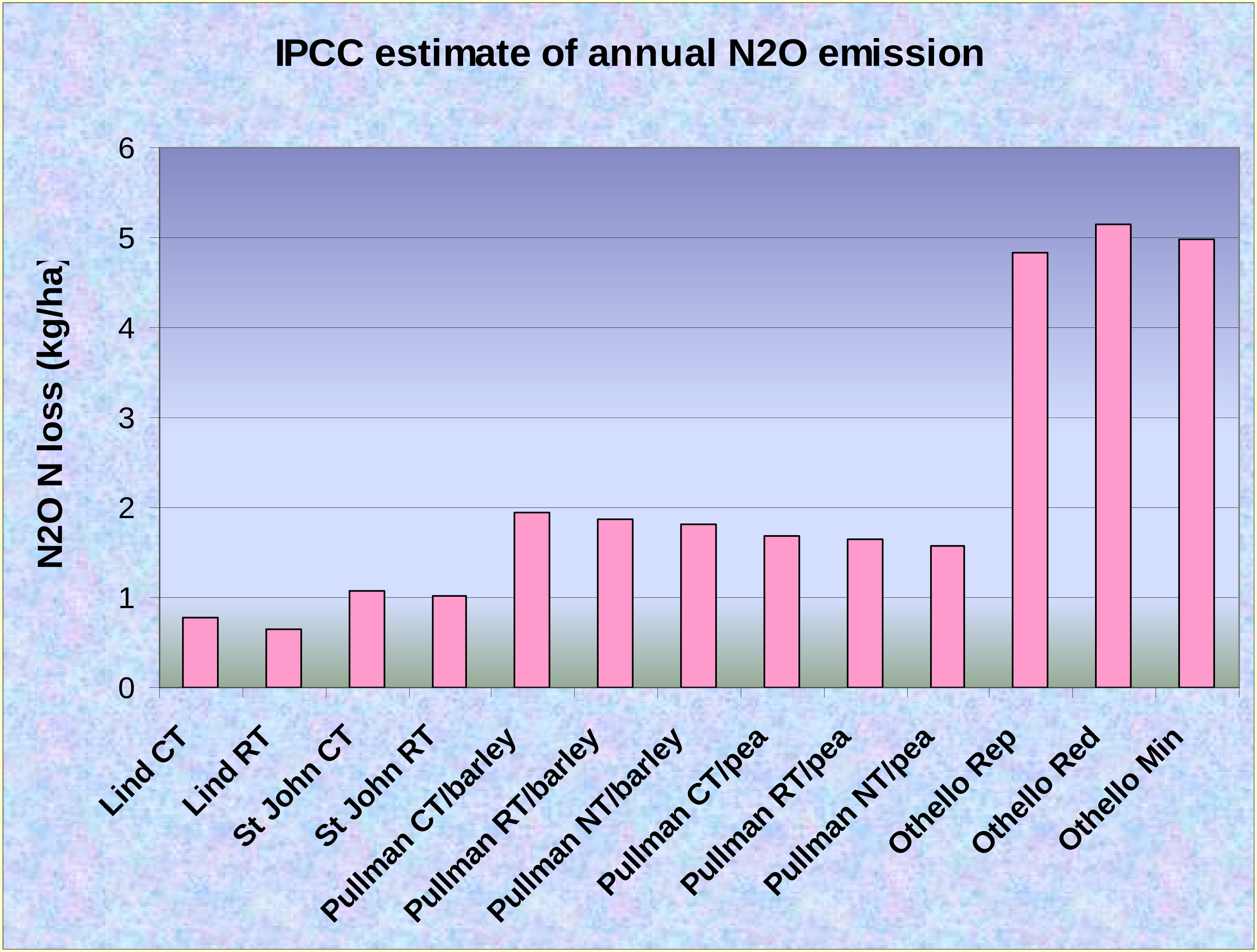

Othello soil profile C
Organic C (kg C/ha)
46000
41000
36000
31000
26000
3000
3020
3040
3060
3080
3100
Year of simulation
Rep
Red
Min



Annual carbon sequestration
Carbon (kg CO2/ha/yr)
800
700
600
500
400
300
200
100
0
Lind_CT_WW-SF
Lind_RT_WW-SF
SaintJohn_CT_WW-SW-SF
SaintJohn_RT_WW-SW-SF
Pullman_CT_WW-SW-SB
Pullman_RT_WW-SW-SB
Pullman_NT_WW-SB-SW
Pullman_CT_WW-SW-SP
Pullman_RT_WW-SW-SP
Pullman_NT_WW-SP-SW
Othello_Rep_SC-SC-P-WW
Othello_Red_SC-SC-P
Othello_Min_SC-SC-P



N applied plus N mineralized annually
N available (kg/ha)
0
50
100
150
200
250
300
350
400
450
N mineralized
N applied
Lind CT
Lind RT
St John CT
St John RT
Pullman CT/barley
Pullman RT/barley
Pullman NT/barley
Pullman CT/pea
Pullman RT/pea
Pullman NT/pea
Othello Rep
Othello Red
Othello Min

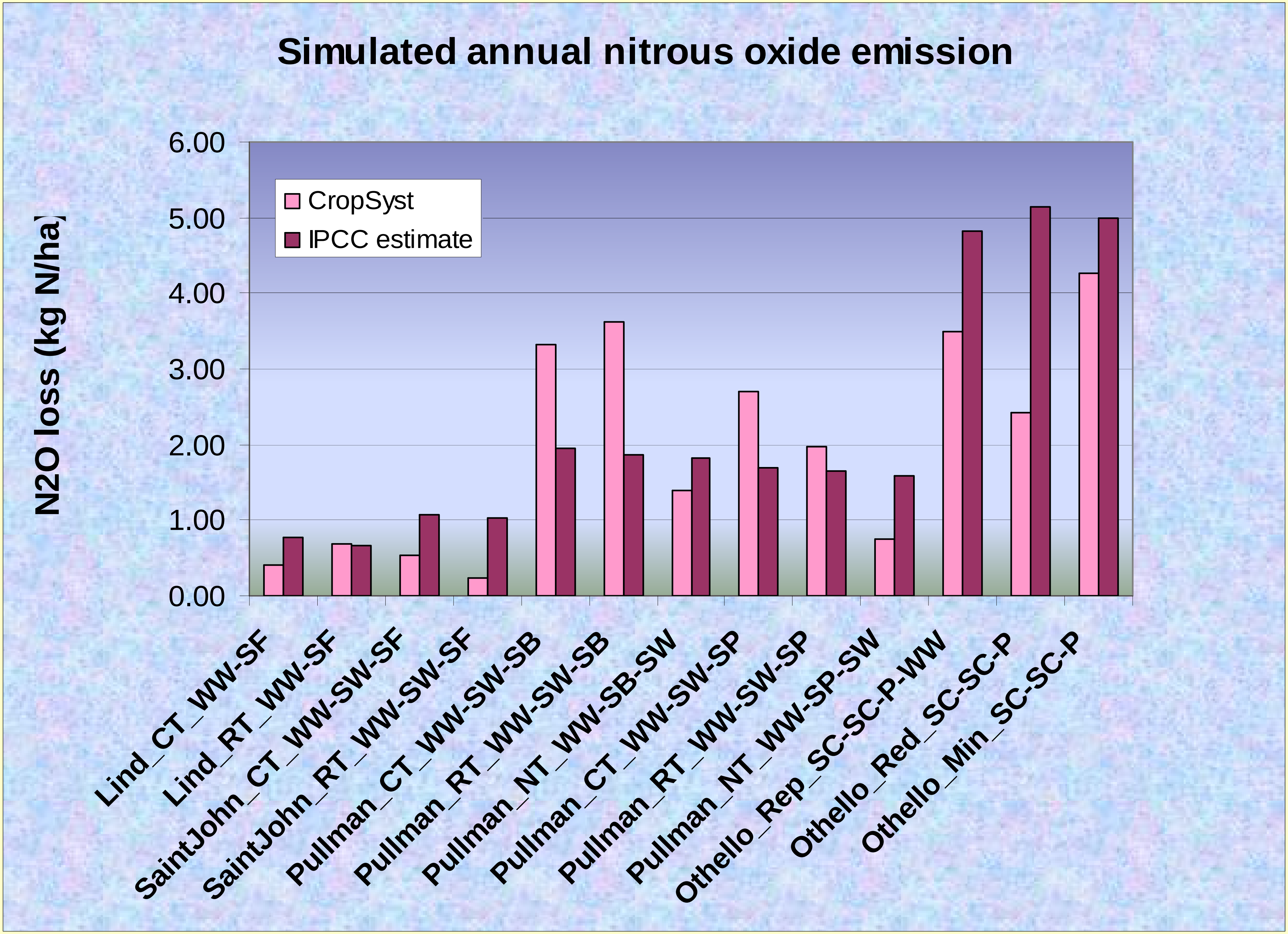

IPCC estimate of annual N2O emission
N2O N loss (kg/ha)
0
1
2
3
4
5
6
Lind CT
Lind RT
St John CT
St John RT
Pullman CT/barley
Pullman RT/barley
Pullman NT/barley
Pullman CT/pea
Pullman RT/pea
Pullman NT/pea
Othello Rep
Othello Red
Othello Min

# $N_2O$ loss, Pullman, WW-SW-SB

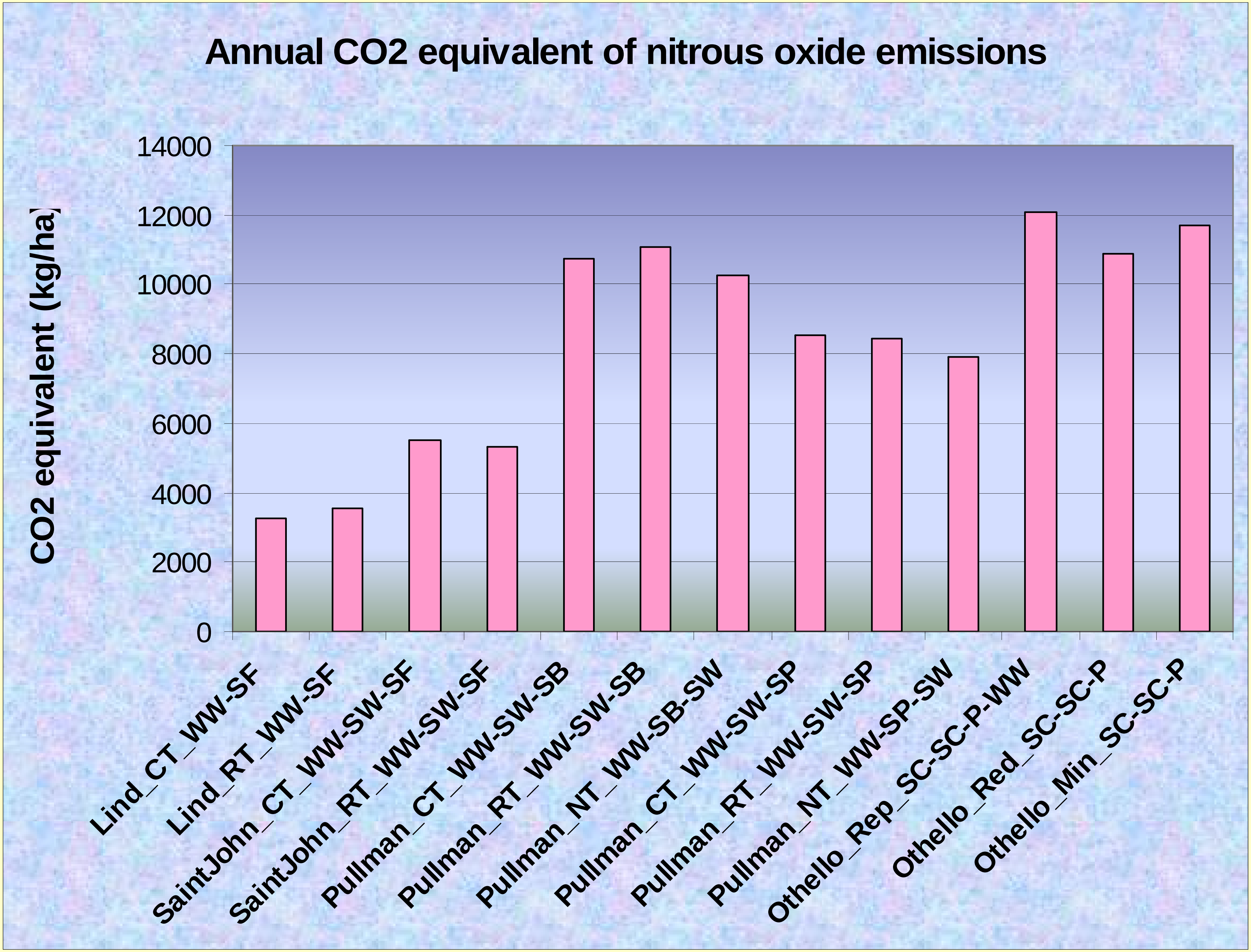
- Measurements made in
  - **May** 372 g/ha
  - **June** 705 g/ha
  - **August** 45 g/ha
  - **October** 45 g/ha
  - Assume 45 g/ha in July and September

- Total $N_2O$ loss during 6 month period:

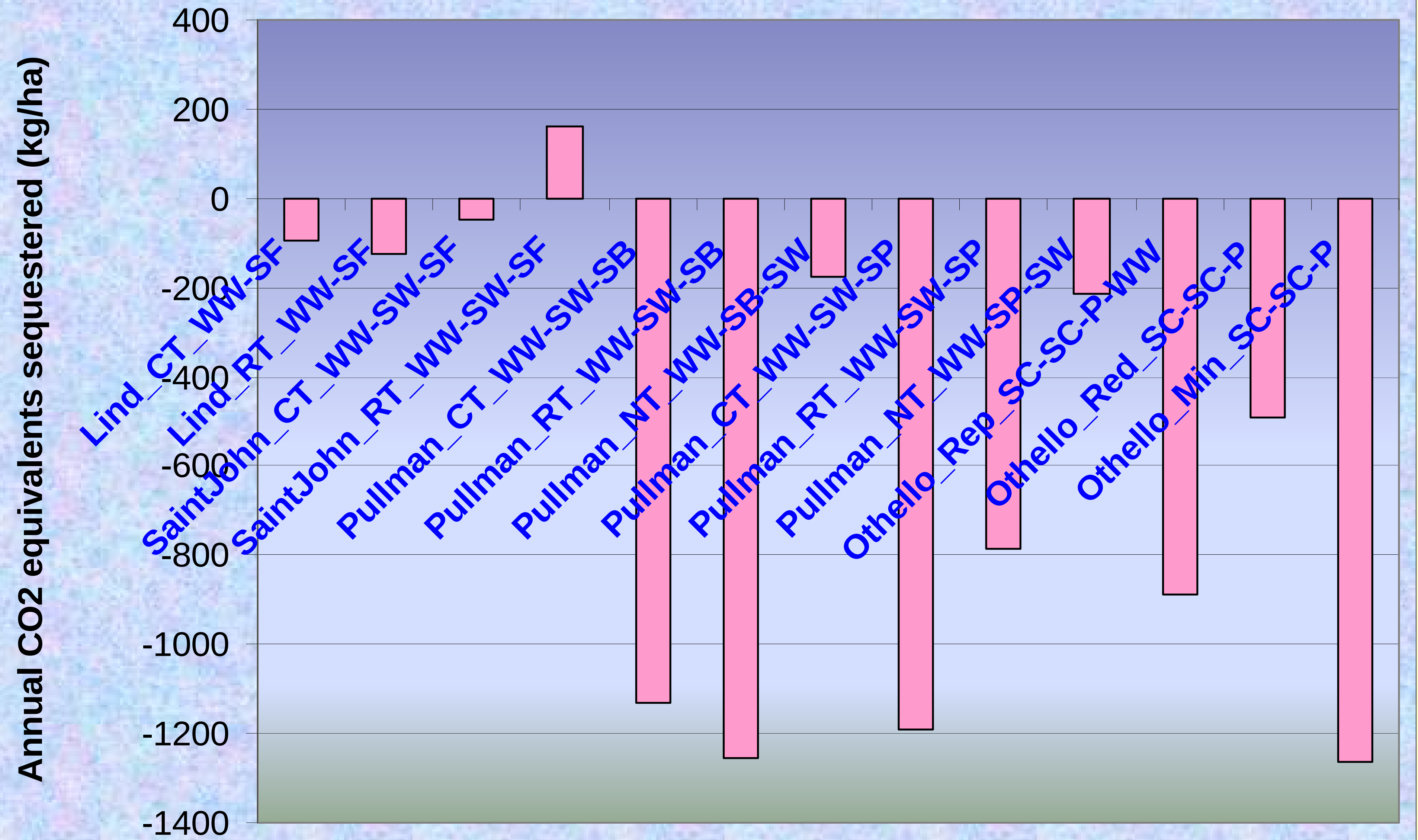
- 1.26 kg $N_2O$-N/ha



Simulated annual nitrous oxide emission
N2O loss (kg N/ha)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
CropSyst
IPCC estimate
Lind_CT_WW-SF
Lind_RT_WW-SF
SaintJohn_CT_WW-SW-SF
SaintJohn_RT_WW-SW-SF
Pullman_CT_WW-SW-SB
Pullman_RT_WW-SW-SB
Pullman_NT_WW-SB-SW
Pullman_CT_WW-SW-SP
Pullman_RT_WW-SW-SP
Pullman_NT_WW-SP-SW
Othello_Rep_SC-SC-P-WW
Othello_Red_SC-SC-P
Othello_Min_SC-SC-P


Annual CO2 equivalent of nitrous oxide emissions
CO2 equivalent (kg/ha)
14000
12000
10000
8000
6000
4000
2000
0
Lind_CT_WW-SF
Lind_RT_WW-SF
SaintJohn_CT_WW-SW-SF
SaintJohn_RT_WW-SW-SF
Pullman_CT_WW-SW-SB
Pullman_RT_WW-SW-SB
Pullman_NT_WW-SB-SW
Pullman_CT_WW-SW-SP
Pullman_RT_WW-SW-SP
Pullman_NT_WW-SP-SW
Othello_Rep_SC-SC-P-WW
Othello_Red_SC-SC-P
Othello_Min_SC-SC-P

# CO2 sequestered - CO2 equivalents of N2O emission



# Conclusions from CropSyst

- For 100-year carbon sequestration, important factors include
  - carbon input
  - initial SOM
  - **tillage (positive effect)**
  - rotation (crop)

# Conclusions from CropSyst

Nitrous oxide emissions can offset gains made in carbon sequestration

# Use of C-Farm as a carbon credit tool

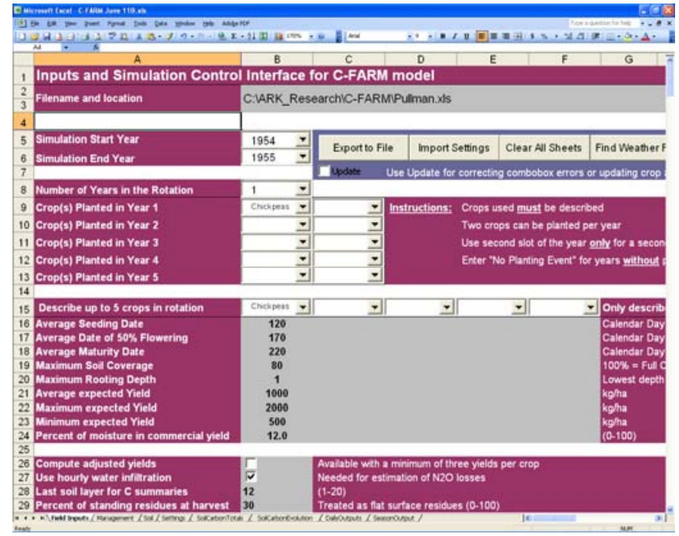
# Develop a tool to compute soil C balance

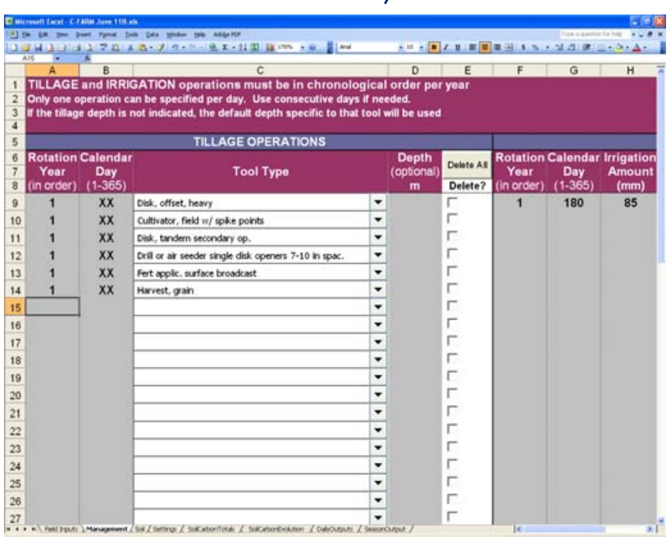
- The following are desirable features of a soil carbon model:
  - Simple structure
  - Consider the entire soil profile
  - No or minimum calibration needs
  - Transferable across locations
  - Consider environmental and management effects on soil carbon turnover
  - Accommodate different management scenarios

# C-FARM Based on MS Excel

## Inputs

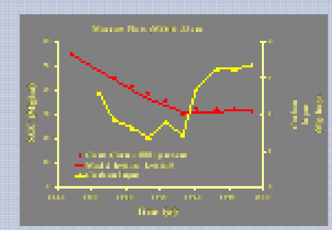
- daily weather
- soil texture and organic carbon by layer
- cropping systems sequence (seeding and maturity dates)
- grain yield (max, min, average) for each crop
- tillage sequence (tools, date, depth of operation)
- Irrigation scheme




## Outputs

- soil organic carbon evolution by layer / year
- estimated carbon input
- estimated humified carbon
- estimated "respired" carbon
- water balance



# Why C-FARM?

- C-FARM is based on grower inputs specifying their own soil, cropping systems and management
  - Available in MS Excel format
  - Pool initialization not required (single pool)
  - Can be applied at the scale of farms or fields within a farm as long as soil, cropping systems, and management information is available
  - Can be used by extension personnel, consultant, and growers with minimum training
  - Can be used as base to develop a generalized Internet-based carbon calculator for the Pacific NW that would provide carbon sequestration information using local inputs

# C-FARM Simulations for Soil Top 30 cm (50 years)

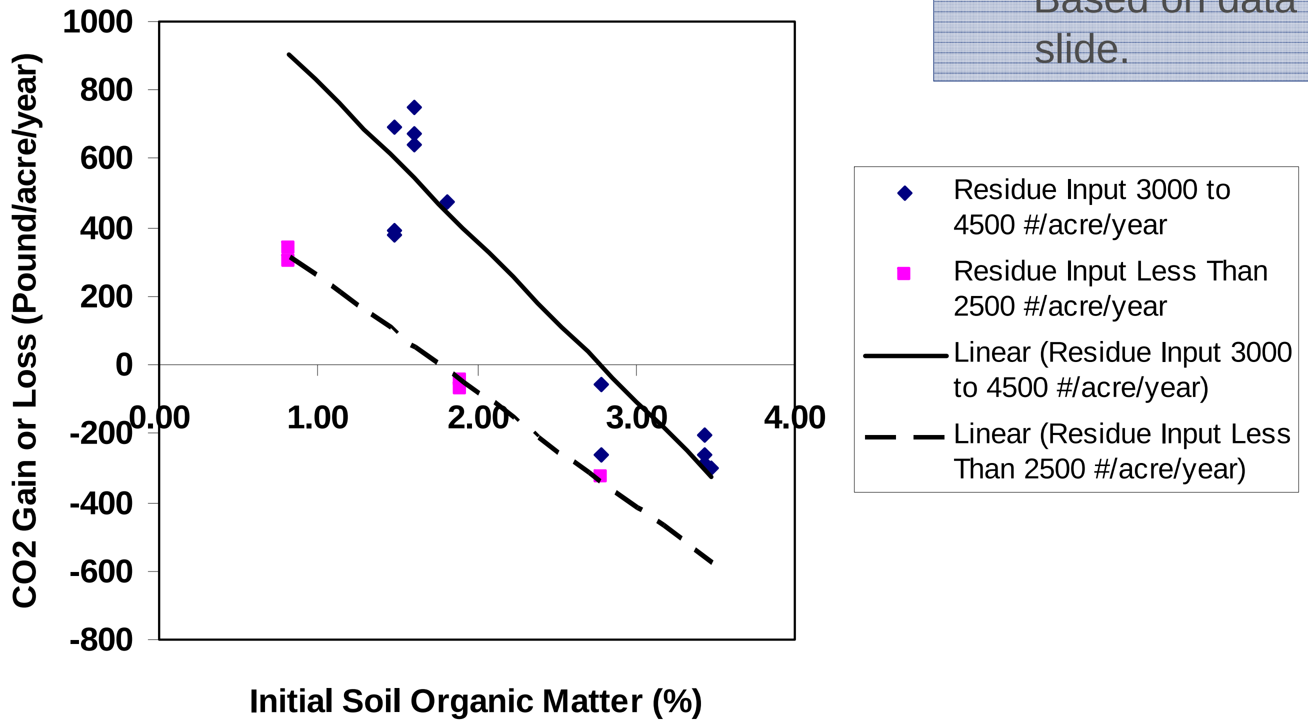
| Location | Rotation | Initial Soil Organic Matter (%) | Final Soil Organic Matter (%) | $CO_2$ Gain or Loss (Pound/acre/year) |
|---|---|---|---|---|
| **Colfax** | **WW-SW-SB-CF** | **3.43** | **2.98** | **-259** |
| **Colfax** | | **1.60** | **1.95** | **671** |
| **Colfax** | **Crn-WW-Crn-Crn** | **3.43** | **2.96** | **-287** |
| **Colfax** | | **1.60** | **1.93** | **644** |
| **Colfax** | **WW-SW-WW-CP** | **3.43** | **3.03** | **-205** |
| **Colfax** | | **1.60** | **2.00** | **752** |
| **Cottonwood** | **WW-SW-F** | **2.78** | **2.41** | **-328** |
| **Cottonwood** | | **1.49** | **1.68** | **381** |
| **Cottonwood** | **WW-SW-SC** | **2.78** | **2.47** | **-259** |
| **Cottonwood** | | **1.49** | **1.69** | **391** |
| **Cottonwood** | **WC-WW-SC-WW-F** | **2.78** | **2.60** | **-56** |
| **Cottonwood** | | **1.49** | **1.88** | **690** |
| **Davenport** | **SB-SW-SW-WW** | **3.48** | **3.09** | **-300** |
| **Davenport** | | **1.82** | **2.05** | **477** |
| **Heppner** | **WW-F** | **1.90** | **1.75** | **-71** |
| **Heppner** | | **0.82** | **1.00** | **304** |
| **Heppner** | **SB-SC-SW-CF-WW** | **1.90** | **1.78** | **-42** |
| **Heppner** | | **0.82** | **1.03** | **338** |

Initial soil organic matter based on lower and higher end values from the NRCS STATSGO database

| Key: | |
|---|---|
| **WW** | **winter wheat** |
| **SW** | **spring wheat** |
| **SB** | **spring barley** |
| **CP** | **chickpea** |
| **F** | **fallow** |
| **SC** | **spring canola** |
| **WC** | **winter canola** |
| **CF** | **chem fallow** |

# C-FARM

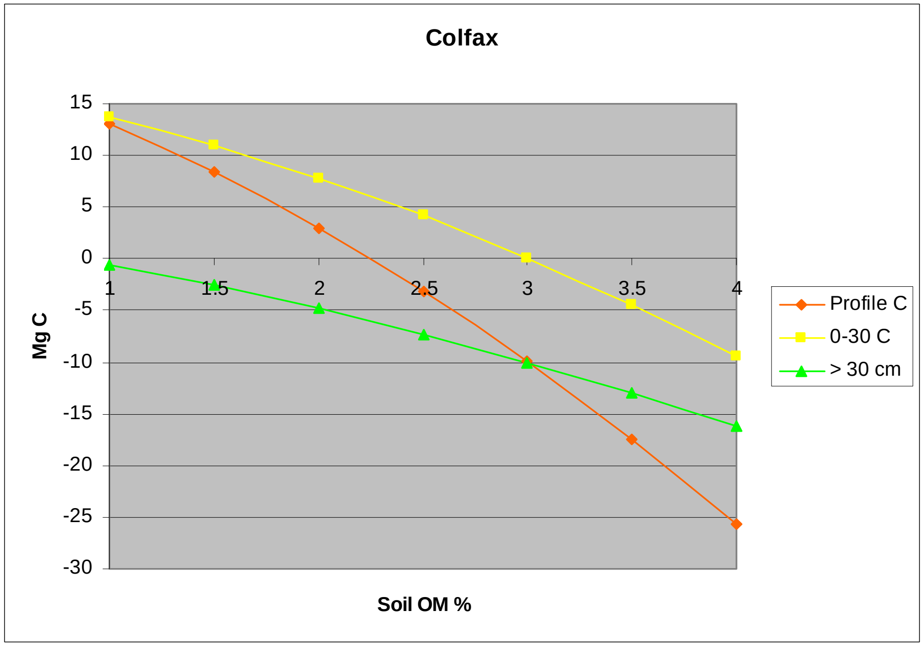
## Measurement of local carbon content and soil clay content is important for better estimation of C sequestration

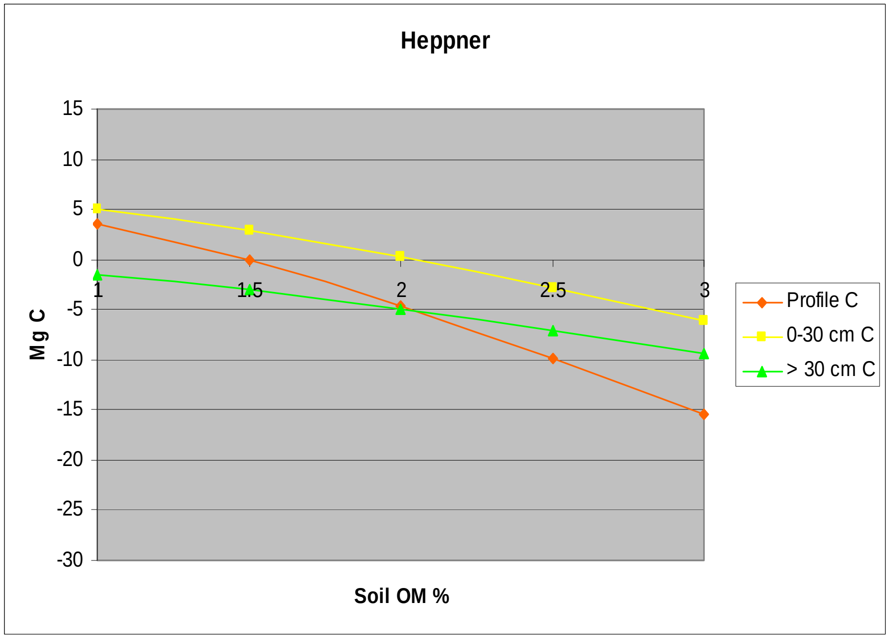



Based on data from previous slide.

High residue input scenarios are likely to store carbon in the top soil if soil organic matter (SOM) is less than 2.5% while low residue input scenarios would require SOM to be less than 1.5% for significant carbon sequestration

# Measurement of local carbon content and soil clay content is important for better estimation of C sequestration




High residue input scenarios are likely to store carbon in the top soil if soil organic matter (SOM) is less than 2.2% while low residue input scenarios would require SOM to be less than 1.5% for significant carbon sequestration

# Conclusions

- C-FARM has the potential to become a useful tool to evaluate the feasibility of carbon sequestration of different cropping systems

- Our simulation results thus far indicate that the main factors defining the SOC sequestration potential of dryland agricultural systems in the US PNW are:

initial SOC (low better than high) > residue input to the soil (high better than low) > tillage intensity (low better than high).