Building Soil Health and Crop Productivity through Potato Cropping Systems

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Soil Health

- Defined as the continued capacity of soil to function as a vital living system to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health

- Emphasis on the importance of all the multiple functions of soil (biomass production, nutrient cycling, filtering and buffering, water storage/ availability, biological habitat, source of biodiversity)

- Encompasses physical, chemical, and biological attributes

- Building and maintaining soil health essential to agricultural sustainability and ecosystem function

Characteristics of Healthy Soils

- High organic matter
- High tilth (loose, friable structure)
- High water-holding capacity and drainage
- Adequate and accessible supply of nutrients
- Sufficient depth for root growth
- Large, diverse populations of beneficial soil organisms, microbial communities
- Low populations of plant pathogens and pests
- Resistant to degradation
- Resilient in ability to recover from stresses

Parameters Associated with Soil Health

- **Physical properties**
  - Texture
  - Bulk density
  - Aggregate stability
  - Water-holding capacity
  - Rooting depth
  - Infiltration
- **Chemical, nutritional properties**
  - Organic matter
  - C, N (Total, active, particulate)
  - P, K, Ca, Mg, Na, CEC
  - pH, EC
- **Biological properties**
  - Microbial biomass, activity
  - Microbial communities, indicator populations
  - Mineralizable N
  - Respiration

Soil Health Management Strategies

- Manage Organic Matter
- Minimize Disturbances
- Diversify Soil Biota
- Maintain Living Plants
- Maintain Soil Cover

HEALTHY SOILS ARE: *high in organic matter.*

Losing Organic Matter

Organic matter is vital to healthy soils, yet most modern agricultural operations are not managed in ways to retain high levels. Only half the original organic matter remains in most modern cultivated soils. In general, organic matter levels have fallen from 5-6 percent of the soil to less than 3 percent on most cropland soils.

Using tillage depletes organic matter. Each time the soil is tilled, oxygen is stirred into it, stimulating microbial action to decompose organic matter at an accelerated rate. As a matter of fact, when a woodland is cleared and planted or a prairie is plowed, most of the organic matter that was built over hundreds of years is lost within 10 years of tillage.

Combining frequent tillage with farming practices that leave little plant residue for soil microbes to eat (such as burning or removing crop residues) will lead to the depletion of organic matter.

unlock the SECRETS IN THE SOIL

ORGANIC MATTER *matters.* IN FACT, THERE MAY BE NO OTHER COMPONENT THAT'S MORE IMPORTANT TO A HEALTHY SOIL THAN ORGANIC MATTER.

The tiny fraction of soil composed of anything and everything that once lived—organic matter—is more than an indicator of healthy soils.

The carbon in organic matter is the main source of energy for the all-important soil microbes and is also the key for making nutrients available to plants. The list of positive influences high levels of organic matter have on healthy soils includes:

1. Provides a carbon and energy source for soil microbes
2. Stabilizes and holds soil particles together
3. Supplies, stores, and retains such nutrients as nitrogen, phosphorusand sulfur
4. Improves the soil's ability to store and move air and water
5. Contributes to lower soil bulk density and less compaction
6. Makes soil more friable, less sticky, and easier to work
7. Retains carbon from the atmosphere and other sources
8. Reduces the negative environmental effects of pesticides, heavy metals and other pollutants
9. Improves soil tilth in surface horizons
10. Increases water infiltration rates
11. Reduces crusting
12. Reduces water runoff
13. Encourages plant root development and penetration
14. Reduces soil erosion

Importance of Soil Microbiology

- An active, diverse soil microbiology is necessary for decomposition, nutrient cycling and availability, soil structure, breakdown of toxins, and suppression of pathogens and diseases

- Managing soil health is largely a matter of maintaining a suitable habitat for the organisms that make up the soil biology

- Organic matter is primary food source for microorganisms. Diverse soil microbiology is promoted by a diversity of plants and plant types, releasing different sets of organic compounds and interacting with different assemblages of microorganisms

- An active, diverse soil microbiology helps keep pathogen populations in check and interferes with capability to cause disease

Management Practices Associated with Soil Health

- **Crop Rotations**
  - Crop type – disease-suppressive?
  - Length
  - Sequence
- **Cover crops and Green Manures**
- **Organic Amendments**
  - Compost, manure
  - Crop residues, mulches
- **Conservation Tillage**
  - Reduced, minimum, no-till

Soil Health and Disease Management

- **Soilborne diseases are most severe when soil conditions are poor**
  - Inadequate drainage, poor structure
  - Low organic matter, fertility
  - High soil compaction
  - Low microbial biomass and diversity

- **Most practices that improve soil health will also reduce soilborne diseases**
  - Improve conditions for crop growth, less disease
  - Increase microbial biomass, activity, & diversity
  - General disease suppression
  - Increase populations of antagonists

- **Specific disease-suppressive practices and strategies for further disease reduction**

Disease-suppressive crops

- *Brassica* and related crops

- Sudangrass (Sorghum/sudangrass hybrids)

Disease suppression

- Biofumigation – breakdown produces volatile toxic metabolites
- Changes in Soil Microbial Communities
- Most effective as green manures

Prevalent Soilborne Potato Diseases:

Canker/Black Scurf (*Rhizoctonia*)

Common Scab (*Streptomyces*)

Powdery Scab (*Spongospora*)

Verticillium wilt (Verticillium)

Disease-Suppressive Rotation Studies:

- **In initial 2-yr rotation studies, canola and rapeseed rotations consistently reduced soilborne diseases over 8-yr study period, reducing incidence and severity of black scurf by 20-45% and common scab by 15-25% relative to other rotation crops**

- **Addition of a fall cover crop of winter rye following each rotation crop resulted in further reductions in soilborne diseases of 9-20% across all rotation crops**

- **Began a series of dedicated field studies assessing mustard and other *Brassica* crops as green manures for disease-suppression and crop productivity. Later added trials with Sudangrass and different management practices.**

- **Over the last 15 years, many studies conducted in Maine (over 75 individual comparison trials) using various different *Brassica* rotation crops in multiple locations and under different management conditions, with variable, but mostly positive results.**

Overview of Brassica Rotation Trials in Maine: Summary Effects on Yield and Diseases

Combined results from >75 field trials

Parameter	Efficacy and changes				
	Sign # effective /# trials	Effective Trials (%)	Overall avg change (%)	Effective avg change (%)	Range of change (%)
Tuber yield	34/66	52%	+6	+11	-7 to +45
Black scurf	47/66	71%	-27	-40	+20 to -100
Common scab	25/60	42%	-8	-22	+25 to -45
Powdery scab	6/13	46%	-11	-26	+0 to -45
Silver scurf	3/4	75%	-17	-25	+5 to -42
Verticillium wilt	3/3	100%	-20	-20	-8 to -30
White mold	0/2	0%	+15	--	+7 to +23

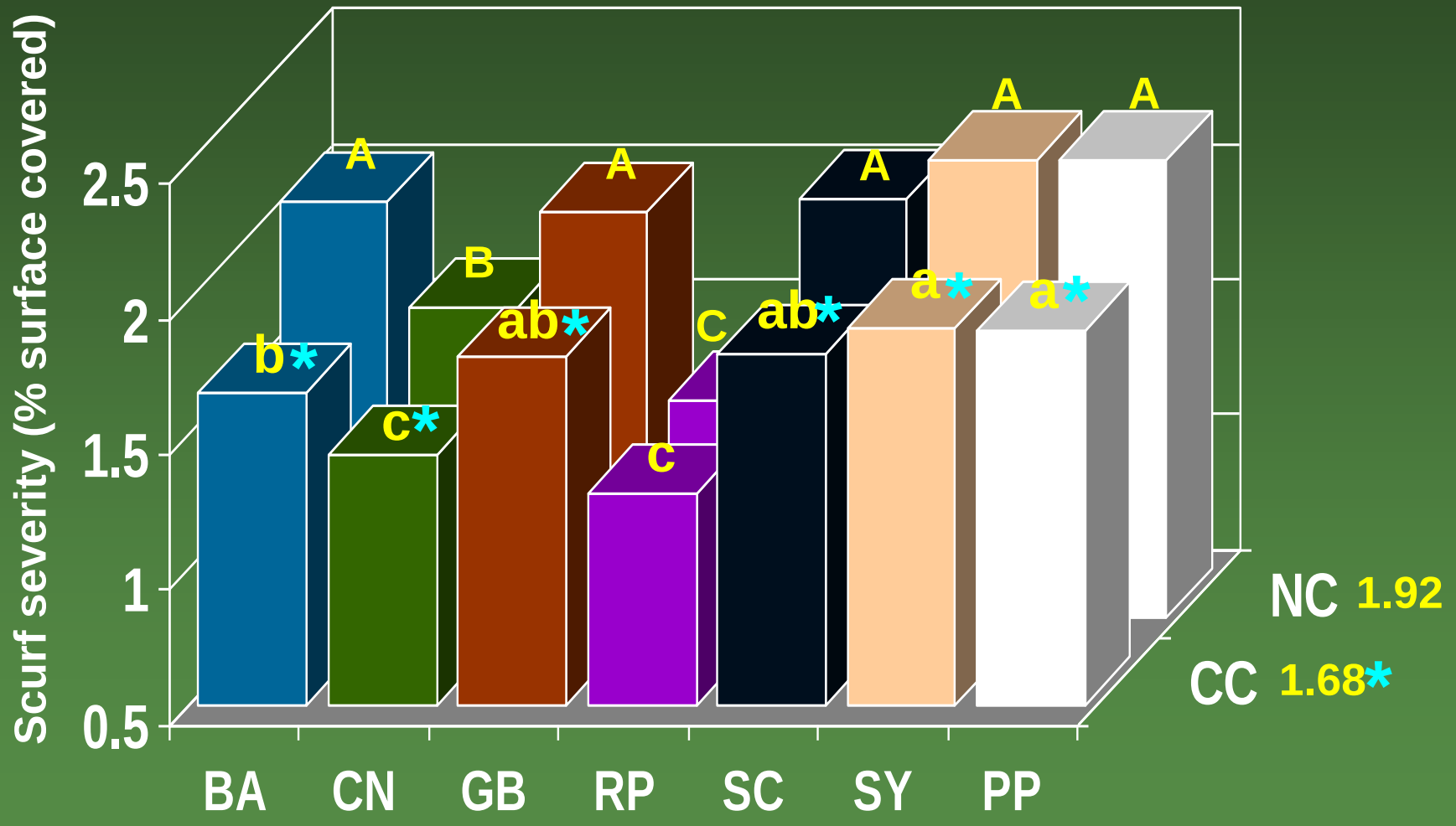
Rotation and Cover Crop Study:

Potato variety: Russet Burbank; 6 rotation crops and cont. potato. Fall cover crop of winter rye added to half of each plot. Cover/No cover comparisons (split-plot).
2-yr rotations (2 entry pts) – 2002-2006

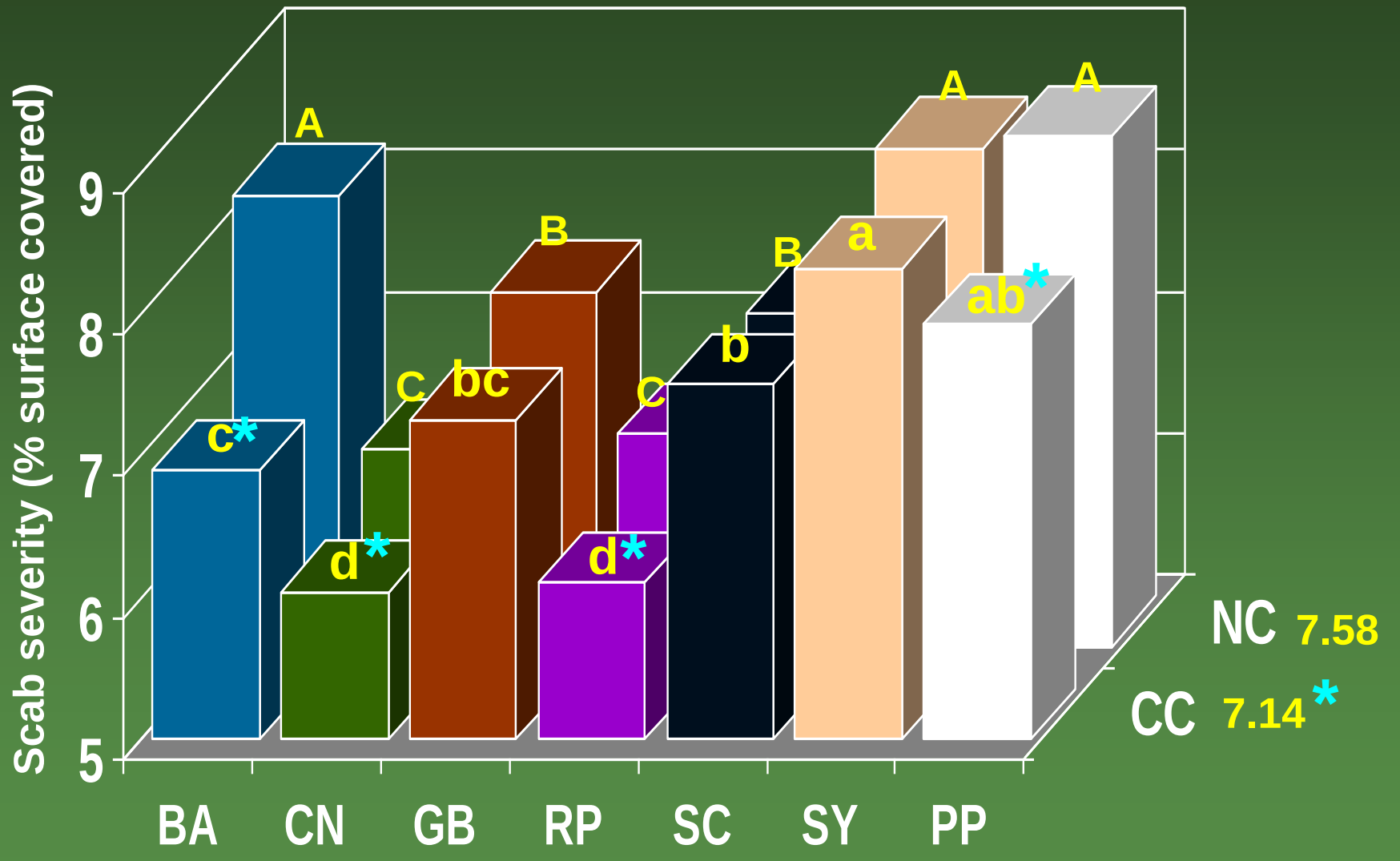
BA - Barley/Clover - Potato
CN - Canola - Potato
GB - Green Bean - Potato
RP - Rapeseed GM - Potato
SC - Sweet Corn - Potato
SY - Soybean - Potato
PP - Potato - Potato

Note: Since barley/clover rotation already included cover crop, the split-plot treatment consisted of a different cover crop used (ryegrass) for cover/no cover comparisons.

Effect of rotation crop with and without a cover crop of winter rye on severity of black scurf (3-yr avg).



Effect of rotation crop with and without a cover crop of winter rye on severity of common scab (3-yr avg).



Crop Management Strategy Study:

Potato variety: Russet Burbank

3-yr rotations (all entry points) – est. 2004; Presque Isle, ME

– continued through 2012

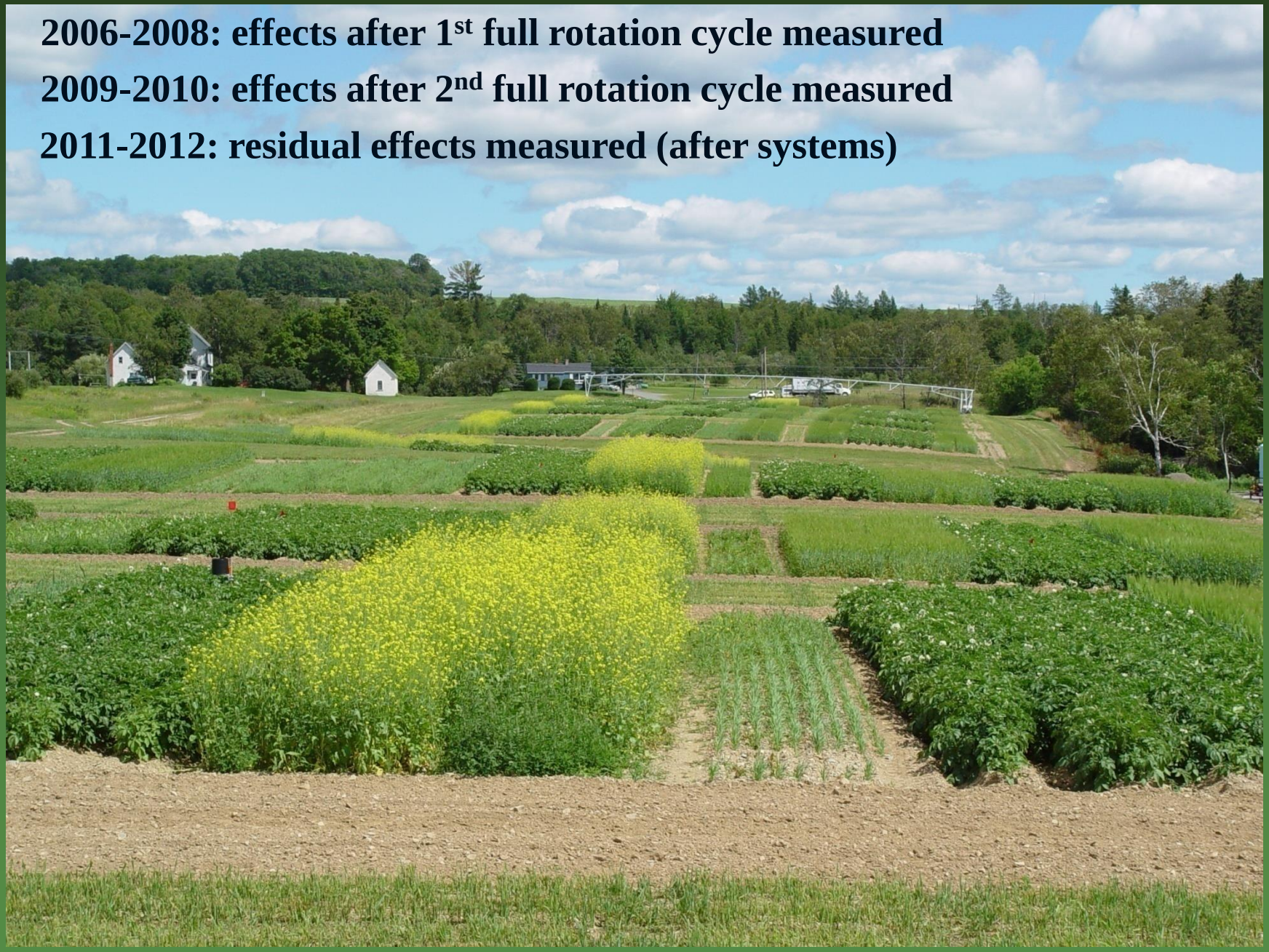
SQ -	**Status Quo (2-yr)**	**Barley (Clover) – Potato** **Standard rotation**
SC -	**Soil Conserving**	**Barley (Timothy) – Timothy** **Limited tillage, straw mulch**
SI -	**Soil Improving**	**Barley (Timothy) – Timothy** **Plus Compost**
DS -	**Disease-Suppressive**	**Mustard GM/rapeseed cover –** **Sudangrass GM/rye cover**
PP -	**Continuous Potato**	**Continuous Potato**

All treatments also implemented under both irrigated (IRR) and non-irrigated (NON) conditions, with irrigation as a split-block factor

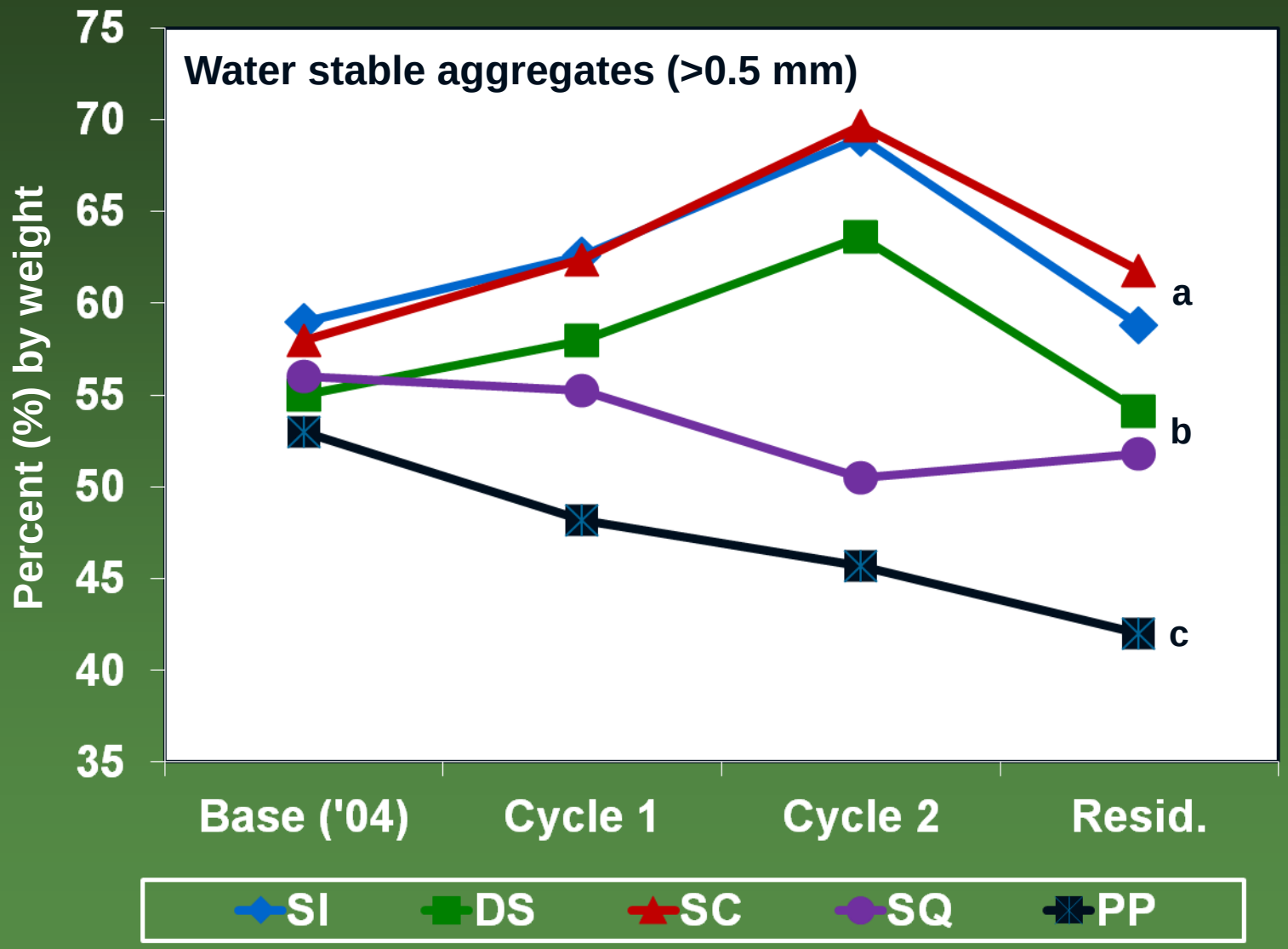
2006-2008: effects after 1st full rotation cycle measured

2009-2010: effects after 2nd full rotation cycle measured

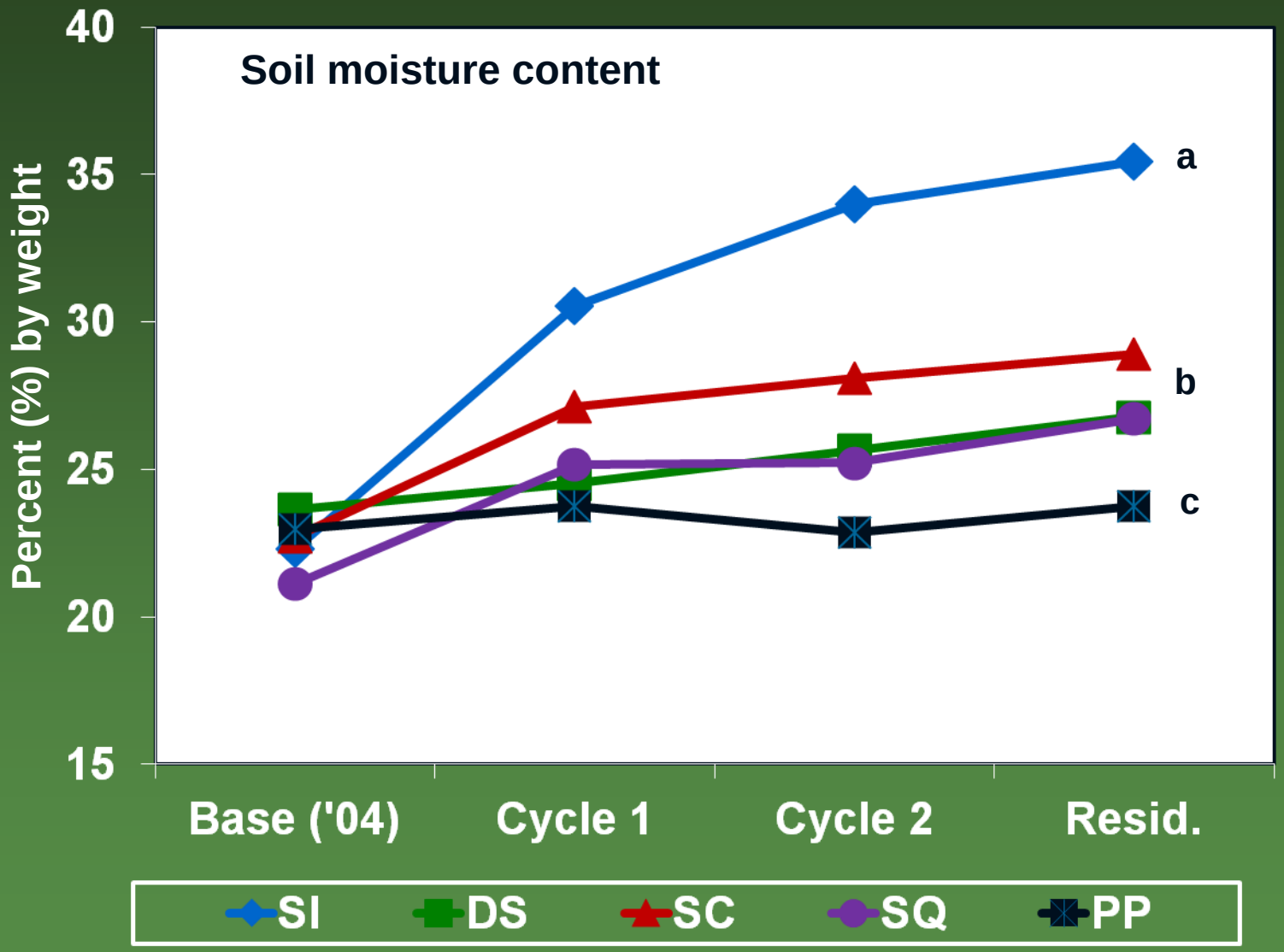
2011-2012: residual effects measured (after systems)



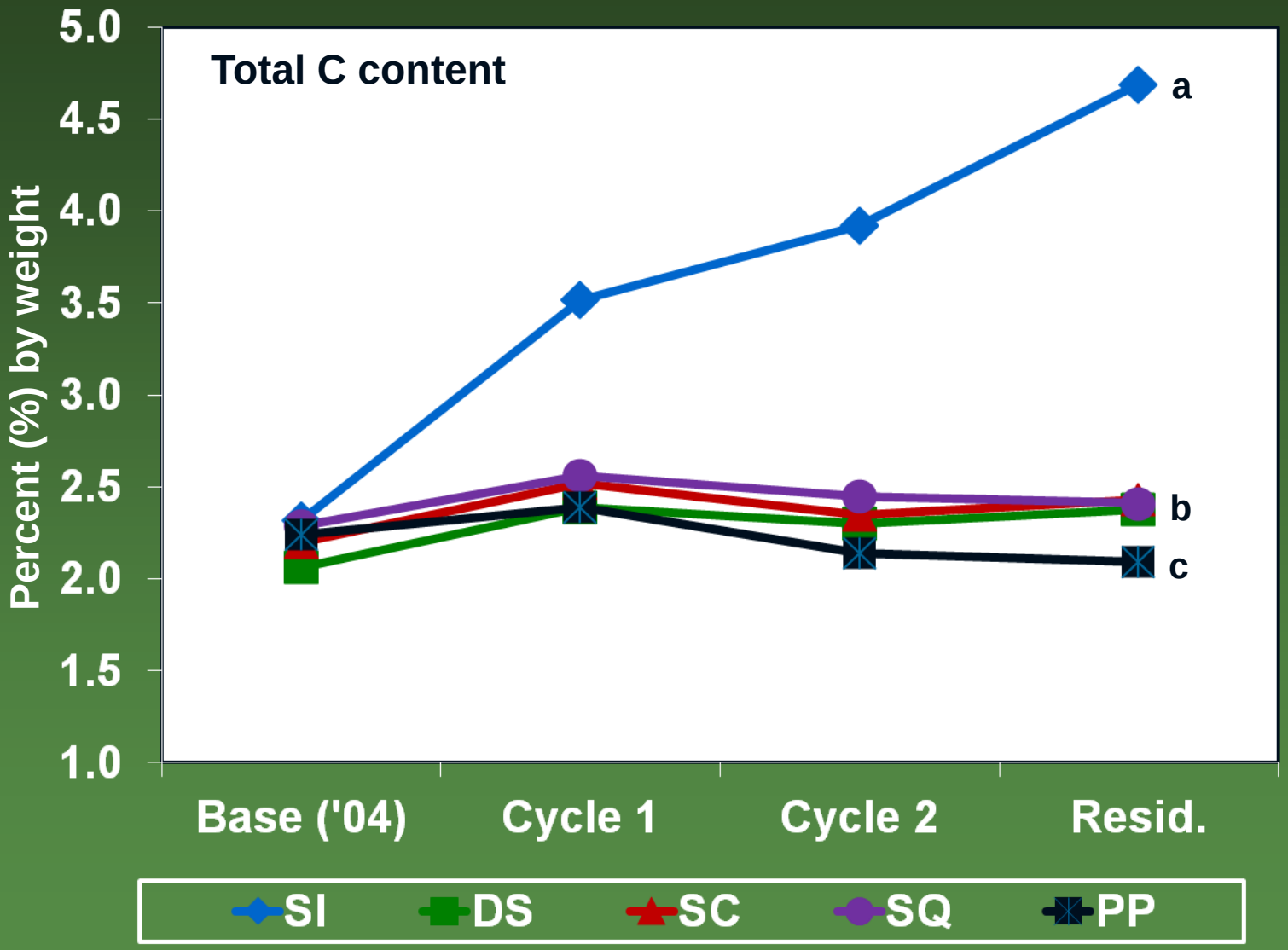
Effect of crop management strategy on soil structure (water stable aggregates) over time (rotation cycles)



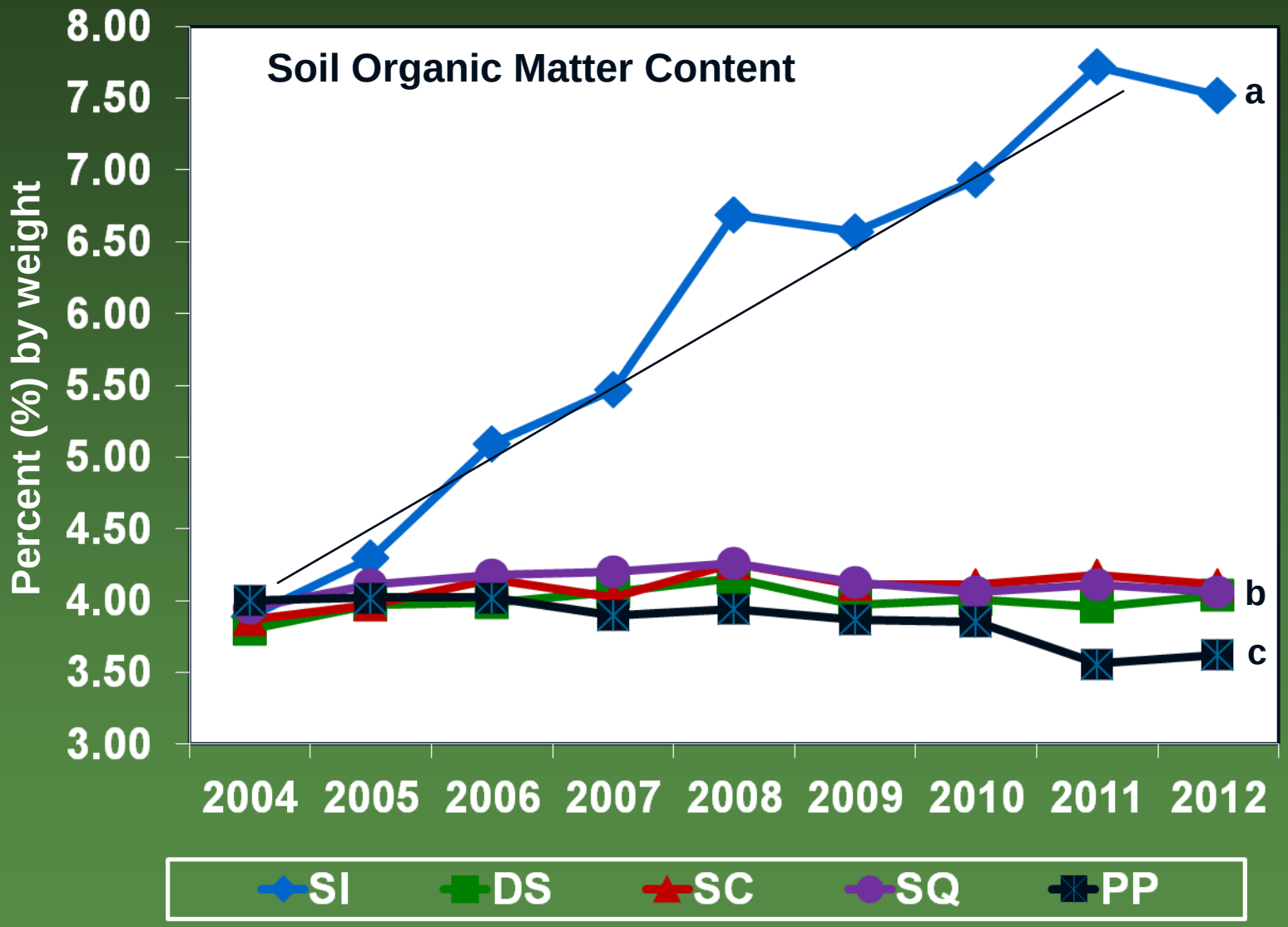
Effect of crop management strategy on soil water availability (moisture content) over time (rotation cycles)



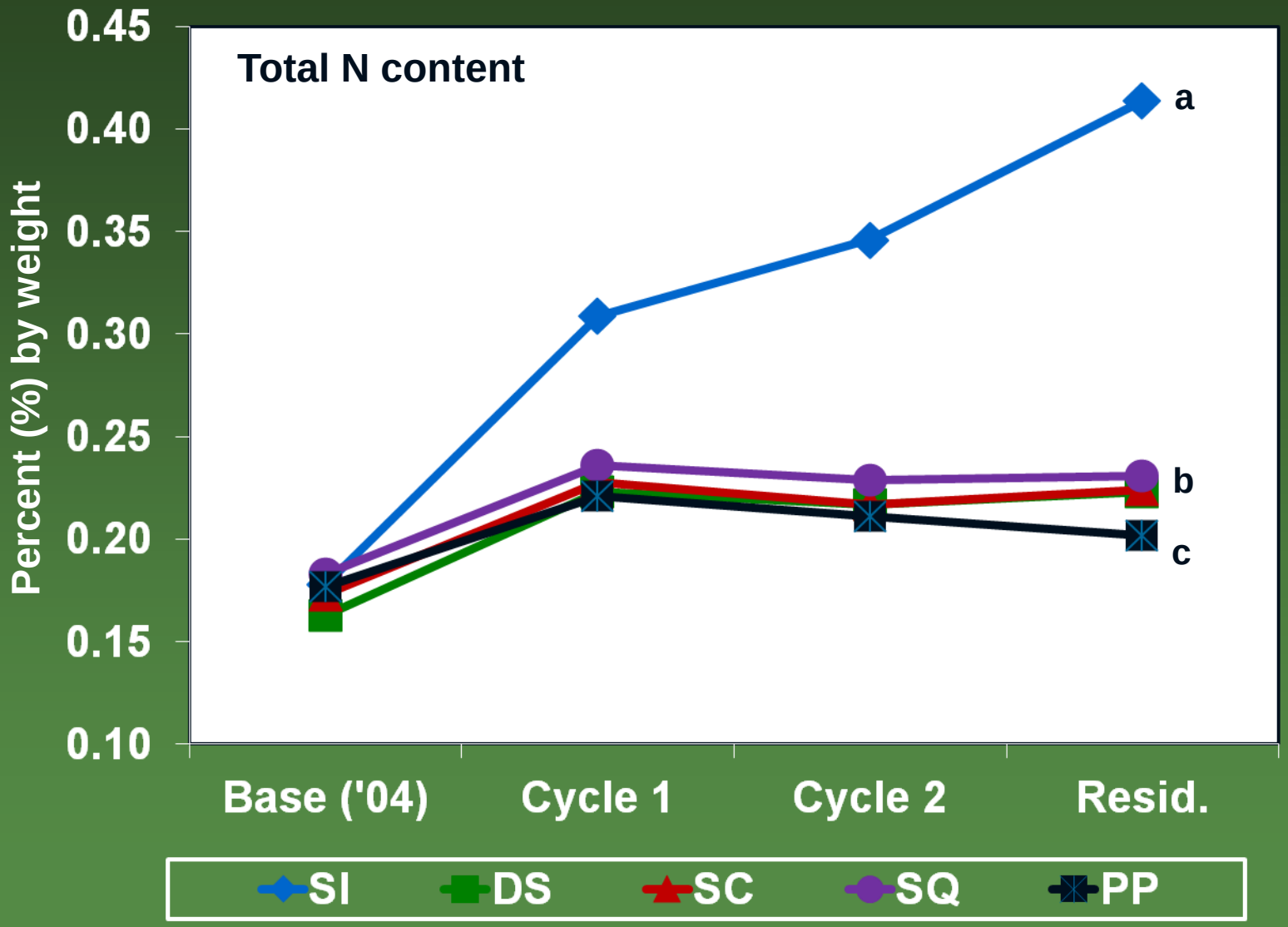
Effect of crop management strategy on soil C content over time (rotation cycles)



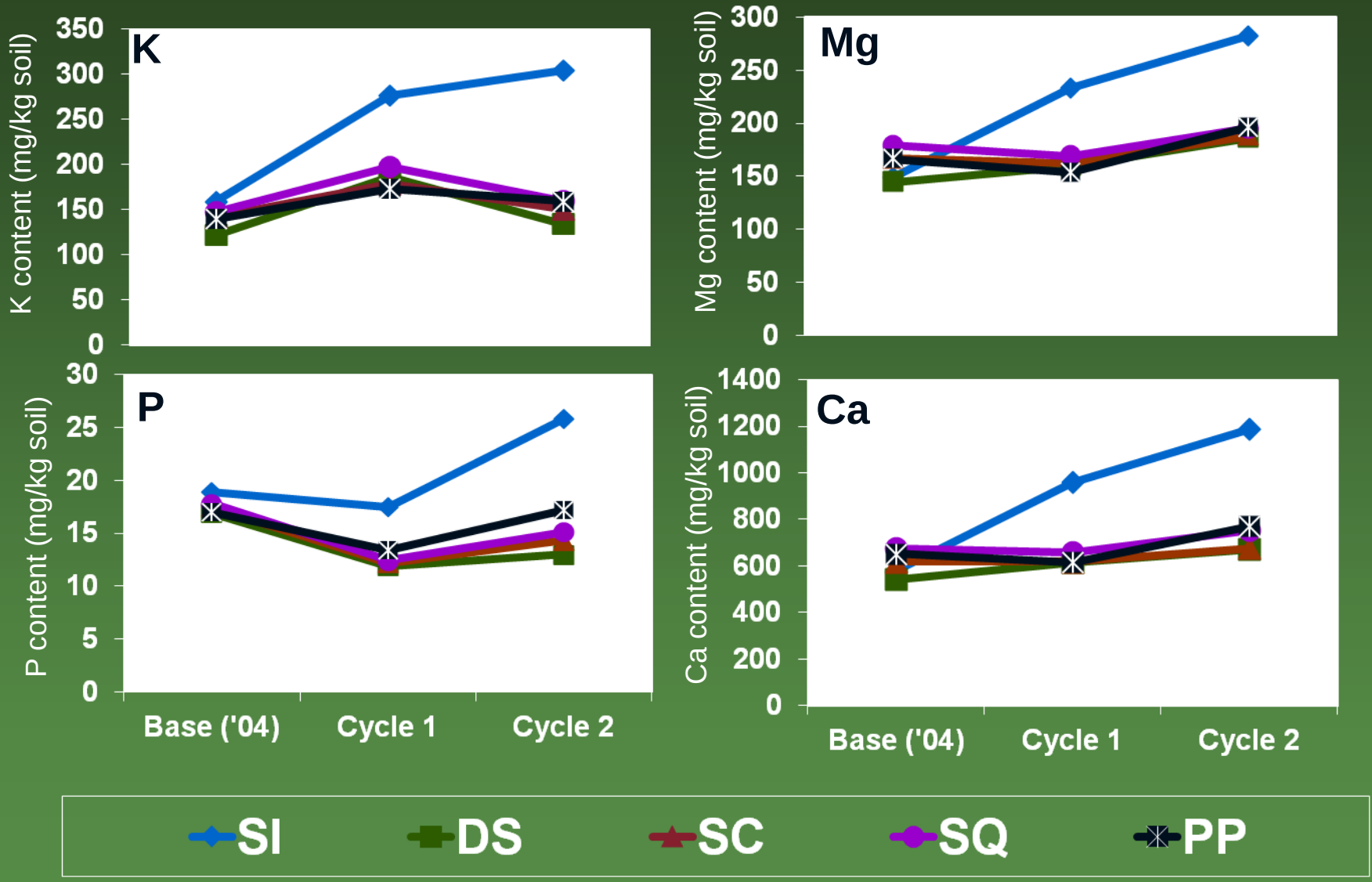
Effect of crop management strategy on soil organic matter content over time



Effect of crop management strategy on soil N content over time (rotation cycles)



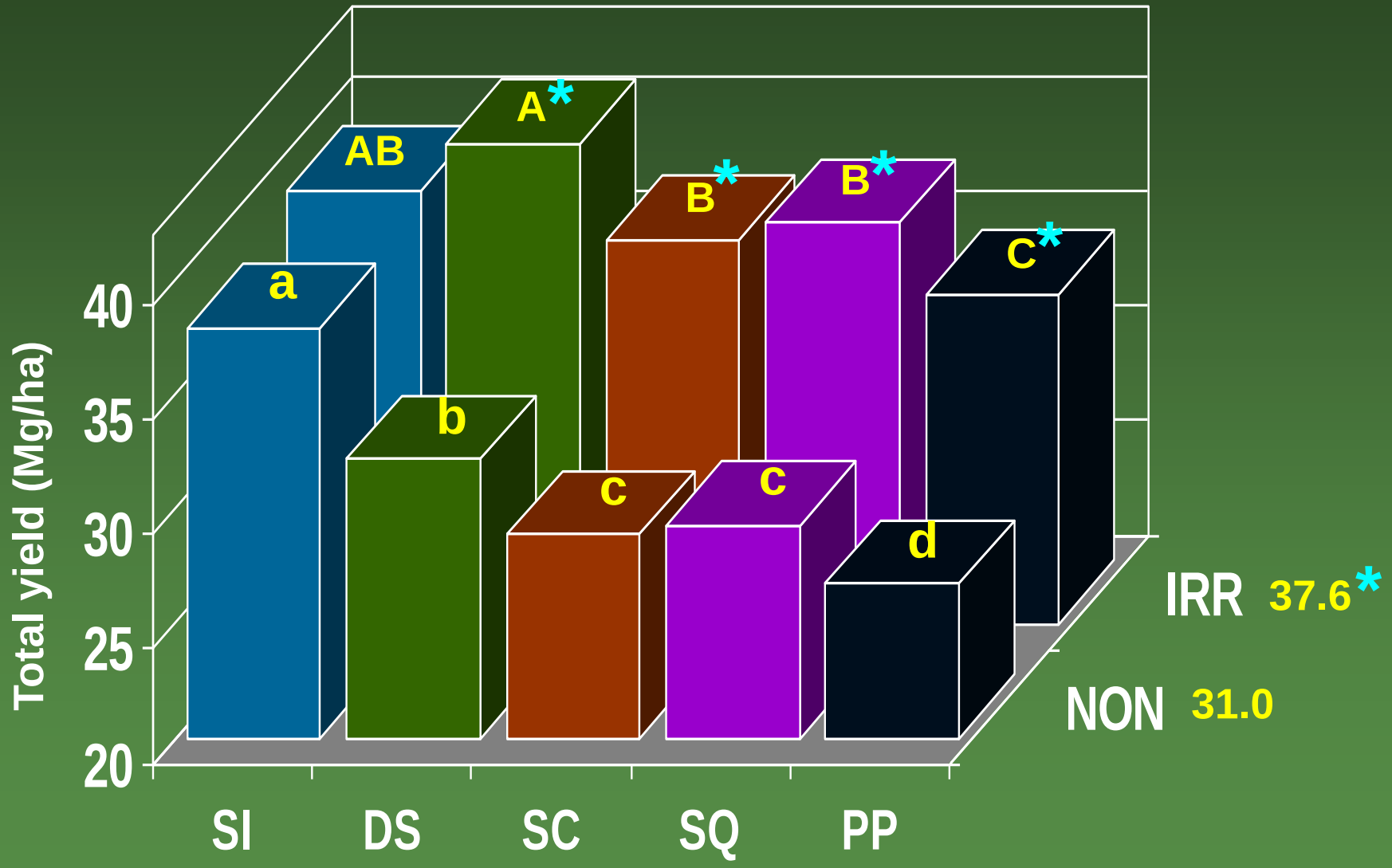
Effect of crop management strategy on soil K, P, Ca, and Mg concentrations after 1st and 2nd full rotation cycles



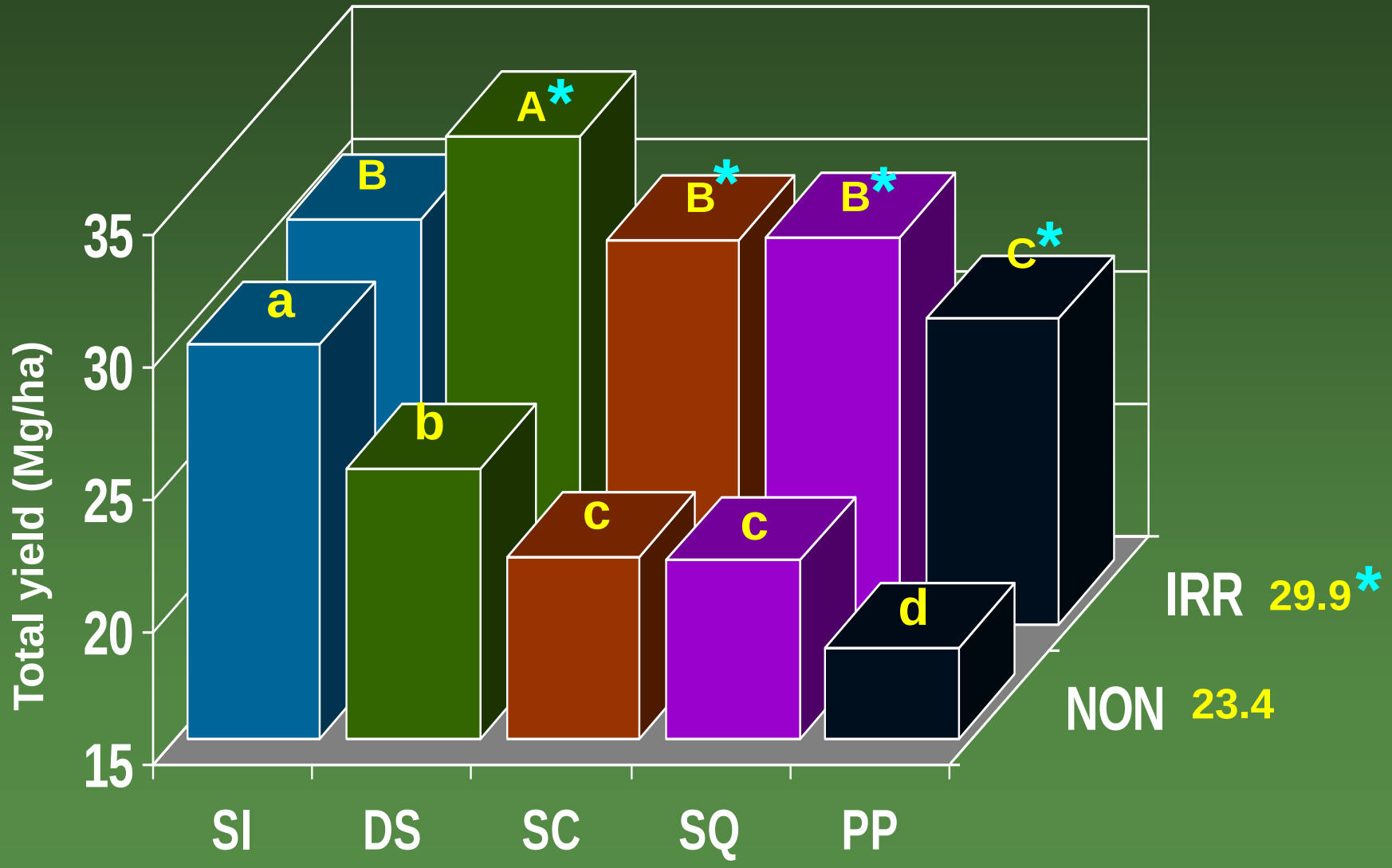
Effect of Management Strategy on Soil Chemical/Biological Properties

Cropping System	Bulk Density (g/cm^3)	Active C (mg C /kg soil)	CEC (meq/100 g)	Microbial biomass C (mg C /kg soil)
SI	0.763 c	562 a	9.0 a	141.5 a
SC	0.856 b	337 cd	5.3 b	99.0 b
DS	0.893 a	346 bc	5.2 b	108.9 b
SQ	0.893 a	363 b	5.8 b	96.1 b
PP	0.904 a	318 d	5.9 b	77.3 c

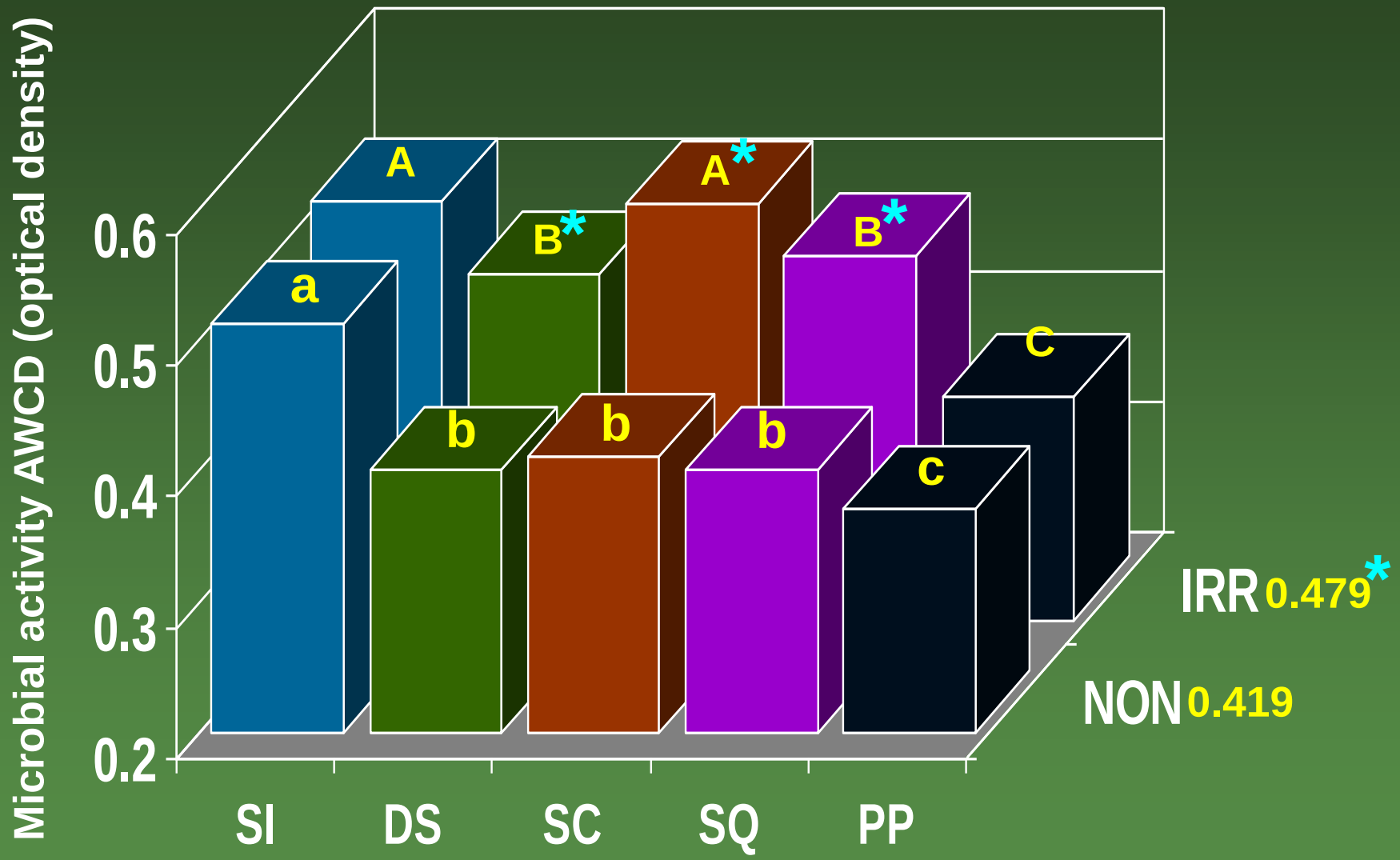
Effect of crop management strategy (3-yr cropping system) with and without irrigation on total tuber yield (5-yr avg).



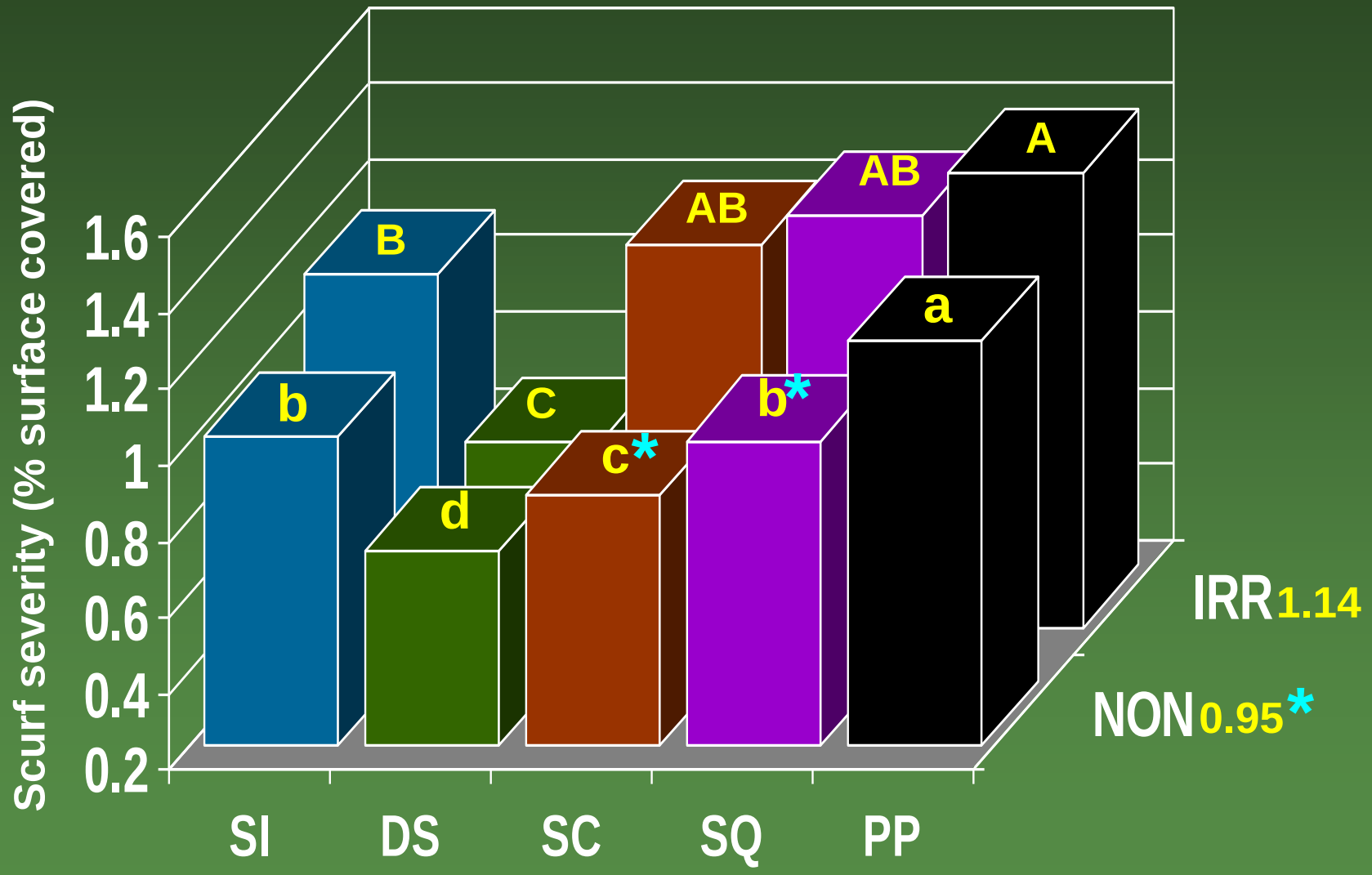
Effect of crop management strategy (3-yr cropping system) with and without irrigation on marketable yield (5-yr avg).



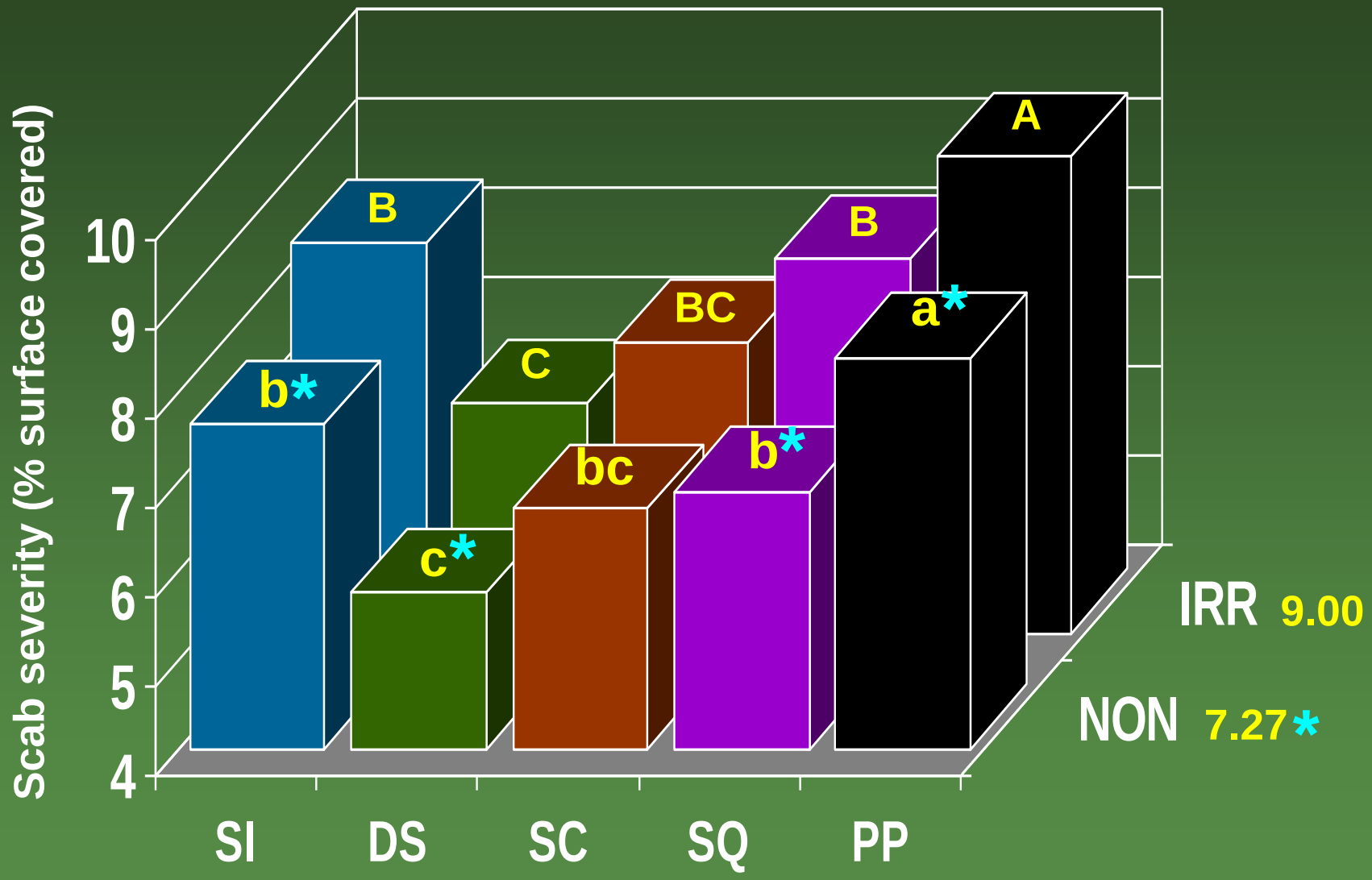
Effect of crop management strategy and irrigation on soil microbial activity (Biolog – AWCD) (after 2nd cycle)



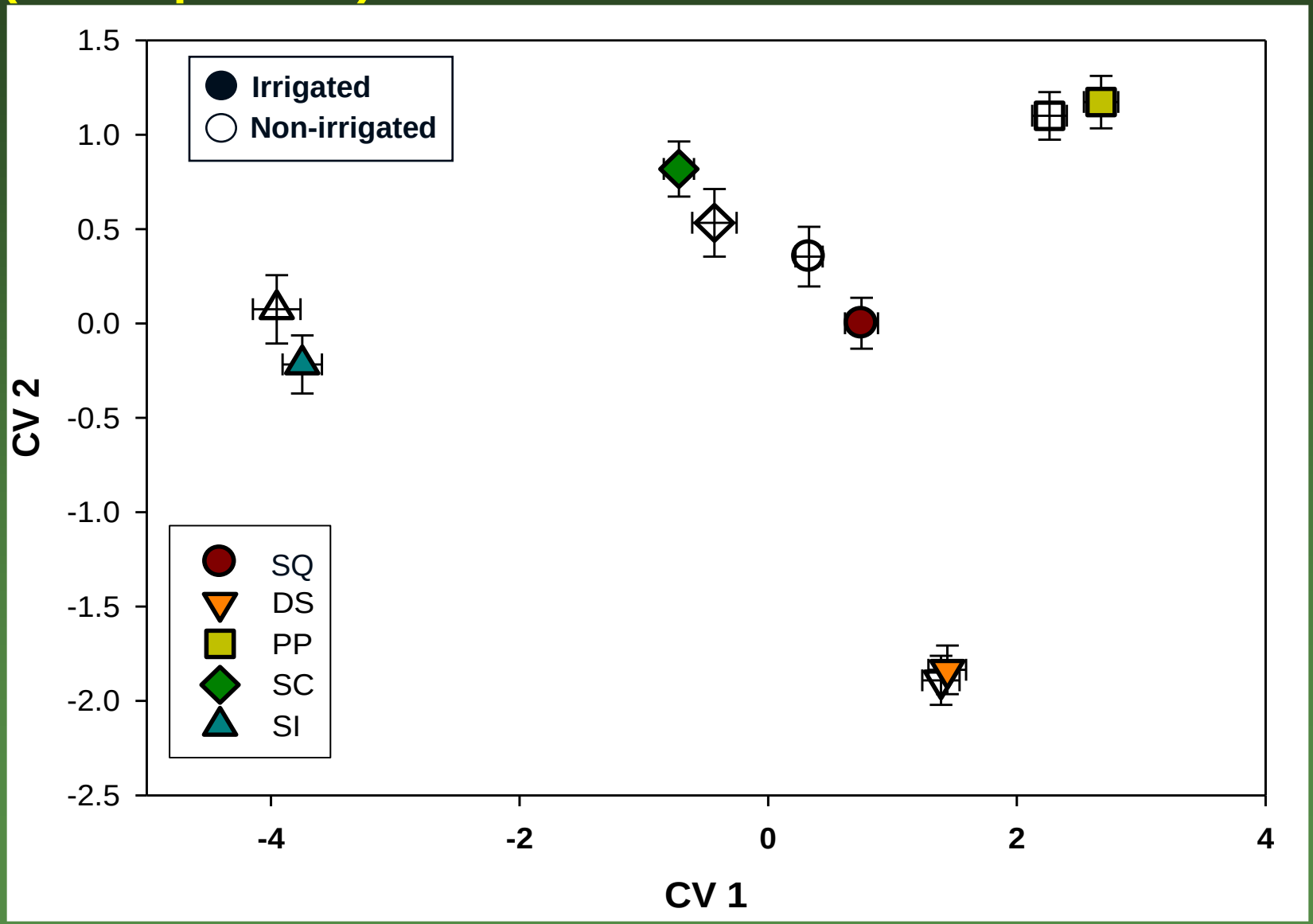
Effect of crop management strategy (3-yr cropping system) with and without irrigation on severity of black scurf (after 2nd rotation cycle)



Effect of crop management strategy with and without irrigation on severity of common scab



Effect of crop management strategy with and without irrigation on soil microbial community characteristics (FAME profiles)



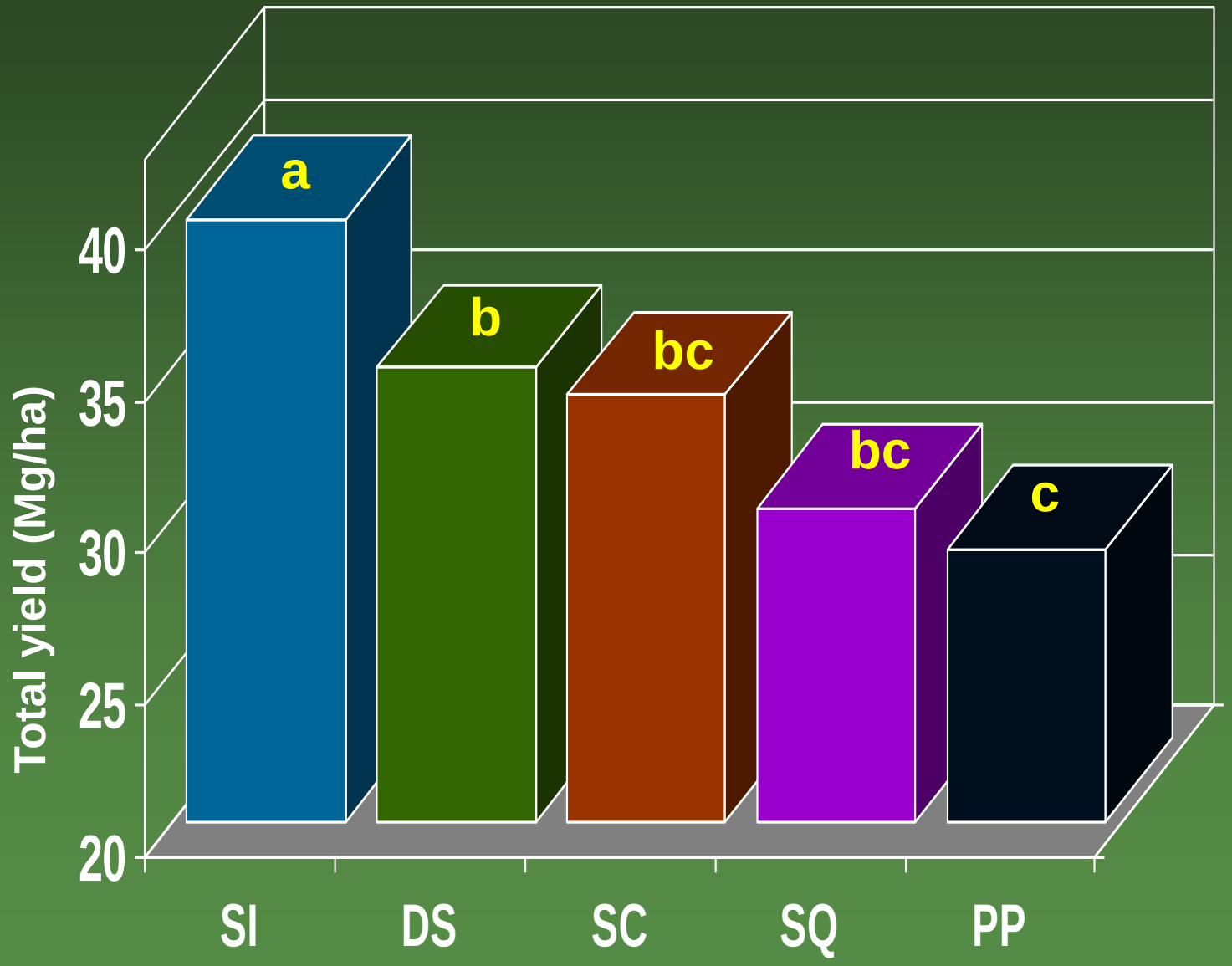
Modified Crop Management Study:

3-yr rotations modified based on previous studies into more practical productive rotations
Est. 2013, in same location, plots as previous study
Potato variety: Russet Burbank - All plots rainfed only (non-irrigated)

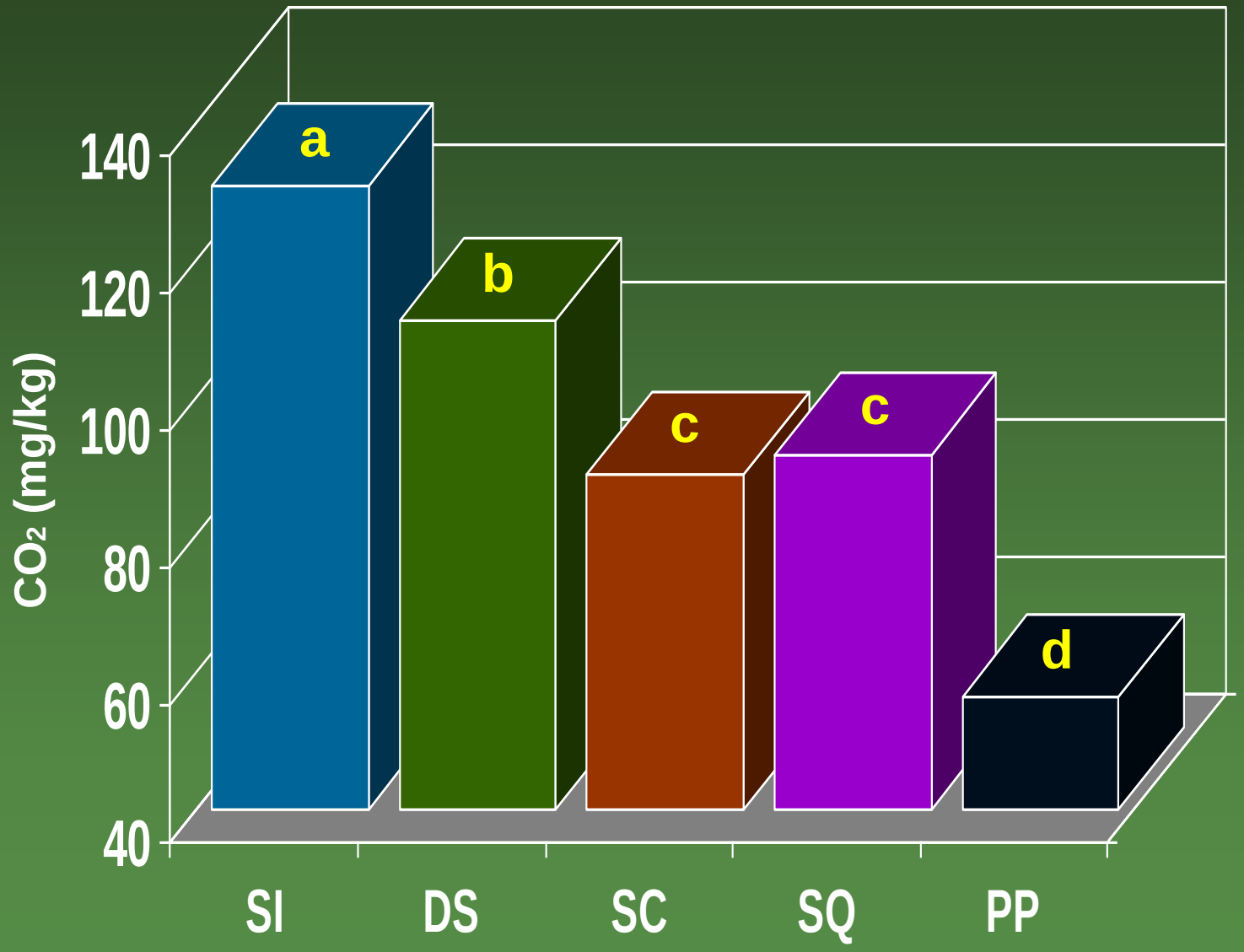
SQ - Same (2-yr)	**Barley (Clover) – Potato**
	Standard rotation
SC - Soil Conserving	**Barley (Ryegrass) – Canola**
SI - Soil Improving	**Barley (Ryegrass) – Canola**
	Plus Compost (only once)
DS - Disease-Suppressive	**Barley (Ryegrass) - Mustard**
	GM/rapeseed cover
PP - Same Cont. Potato	**Continuous Potato**

Evaluated after full rotation cycle completed – 2015 and 2016 cropping seasons

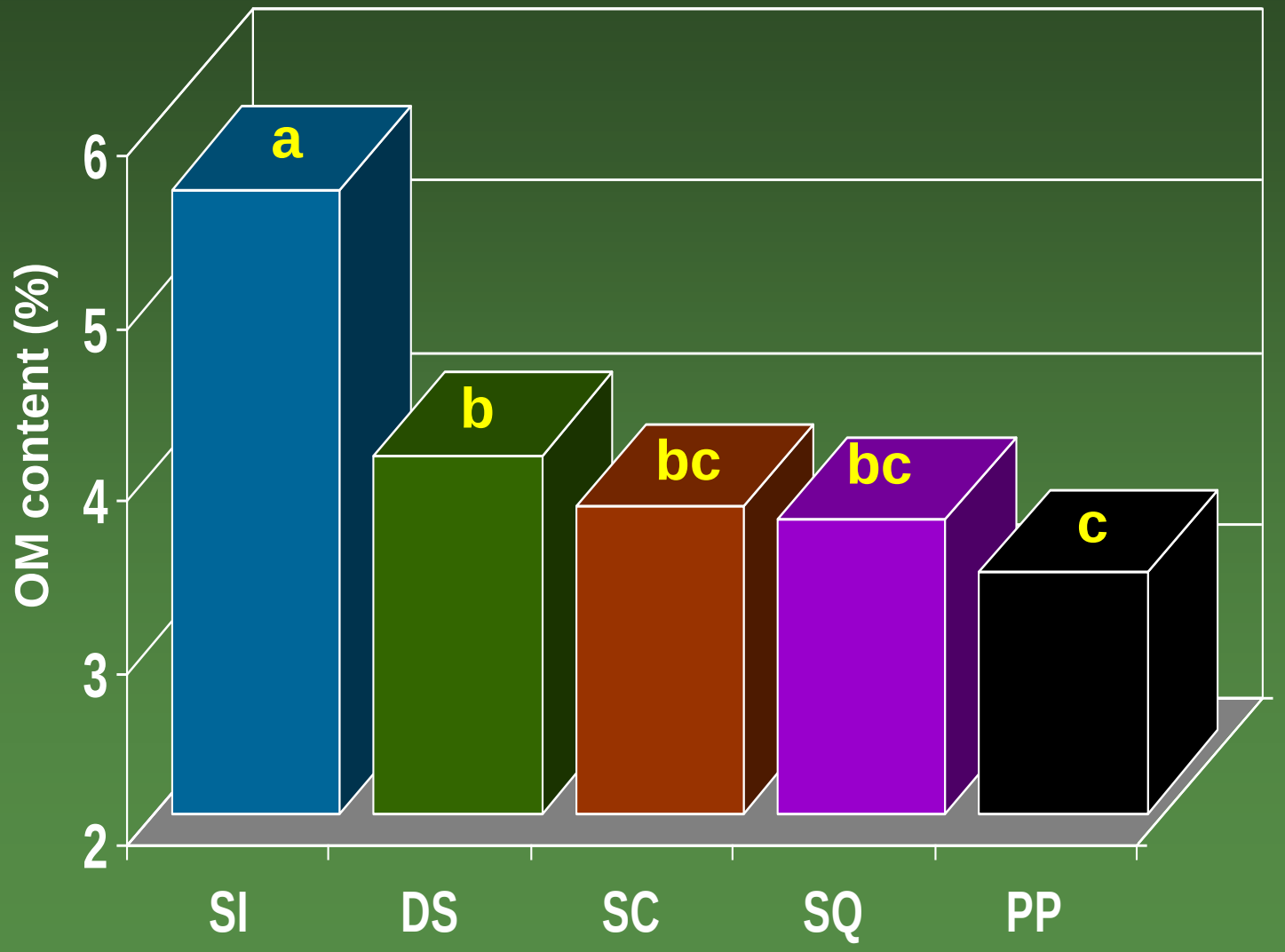
Effect of modified crop management strategy on total tuber yield (avg of 2015-2016 seasons)



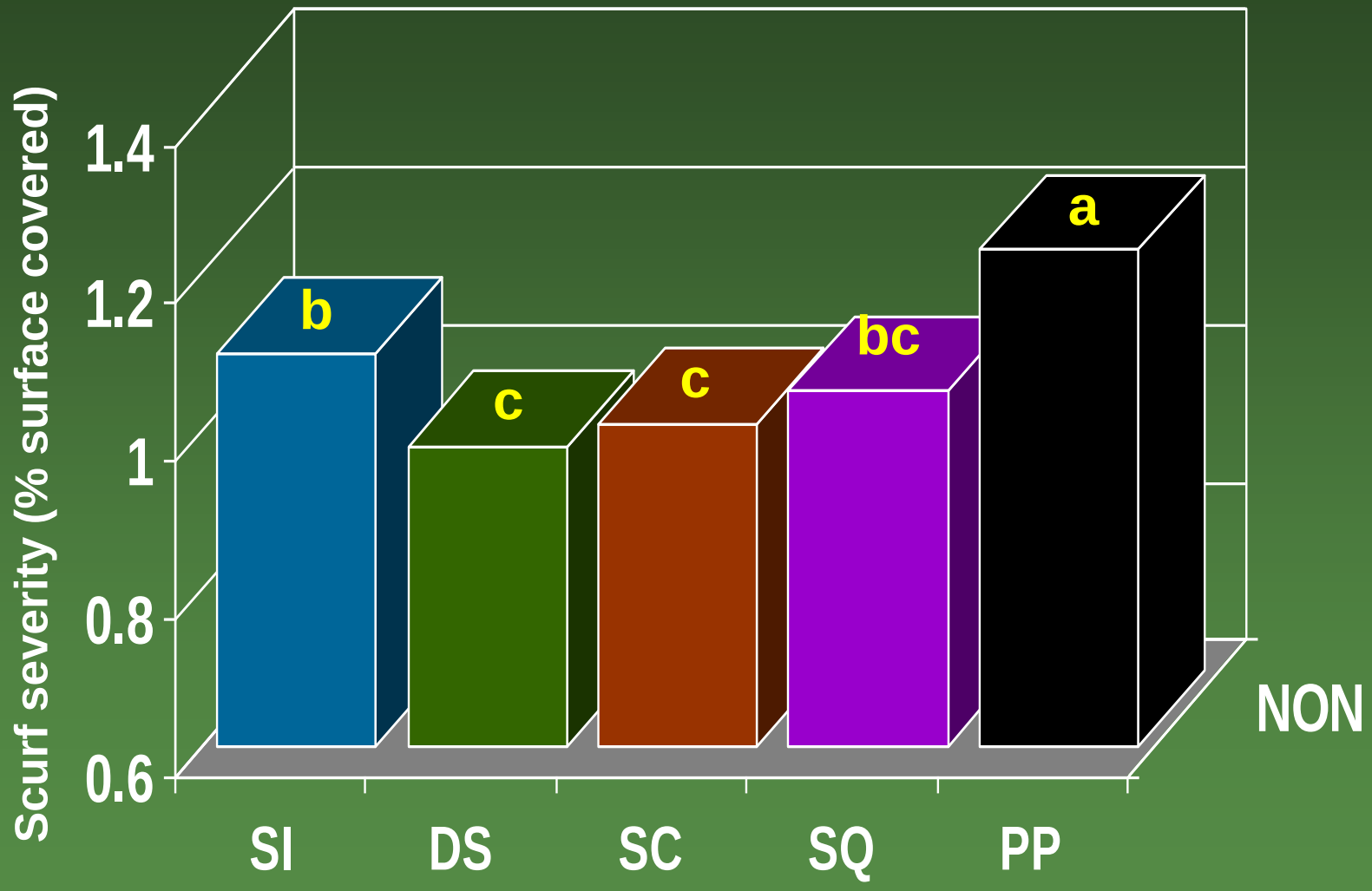
Effect of modified crop management strategy on soil microbial respiration (CO_2 burst - Solvita)



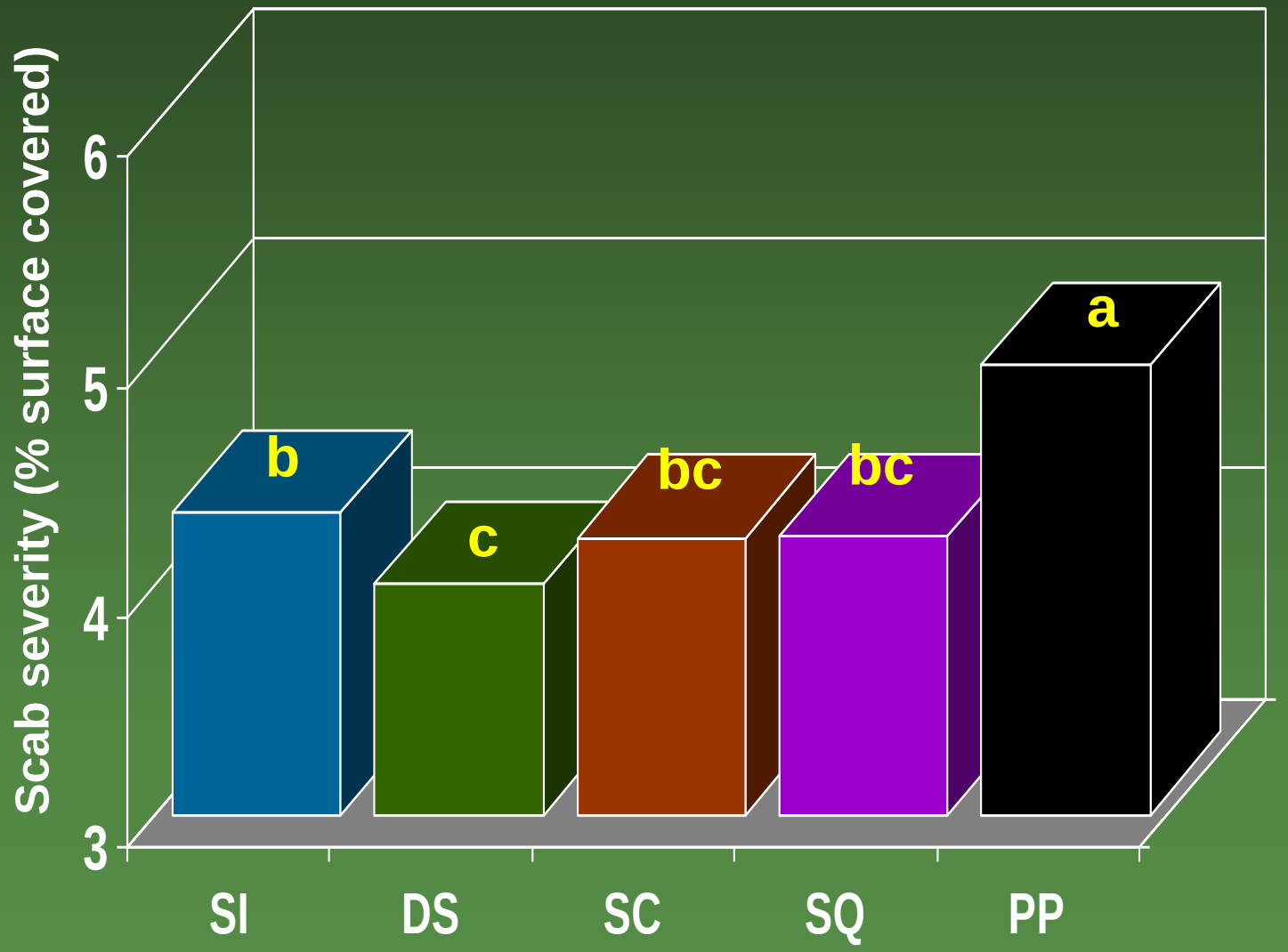
Effect of modified crop management strategy on soil organic matter content (2016 season)



Effect of modified crop management on severity of black scurf (2016 season)



Effect of modified crop management strategy on severity of common scab (2016 season)



Disease-Suppressive Management Studies

Brassica as Fall Cover-GM Crop:
Under Maine conditions, not very practical. Need to plant by first week of August. In warmer climates, can be very effective as fall green manure crop.

Rotation Management Options: Study examined multiple rotation crops under different management practices. 2-yr rotations, each rotation examined over 2 field seasons, repeated
Presque Isle, 2009-2011

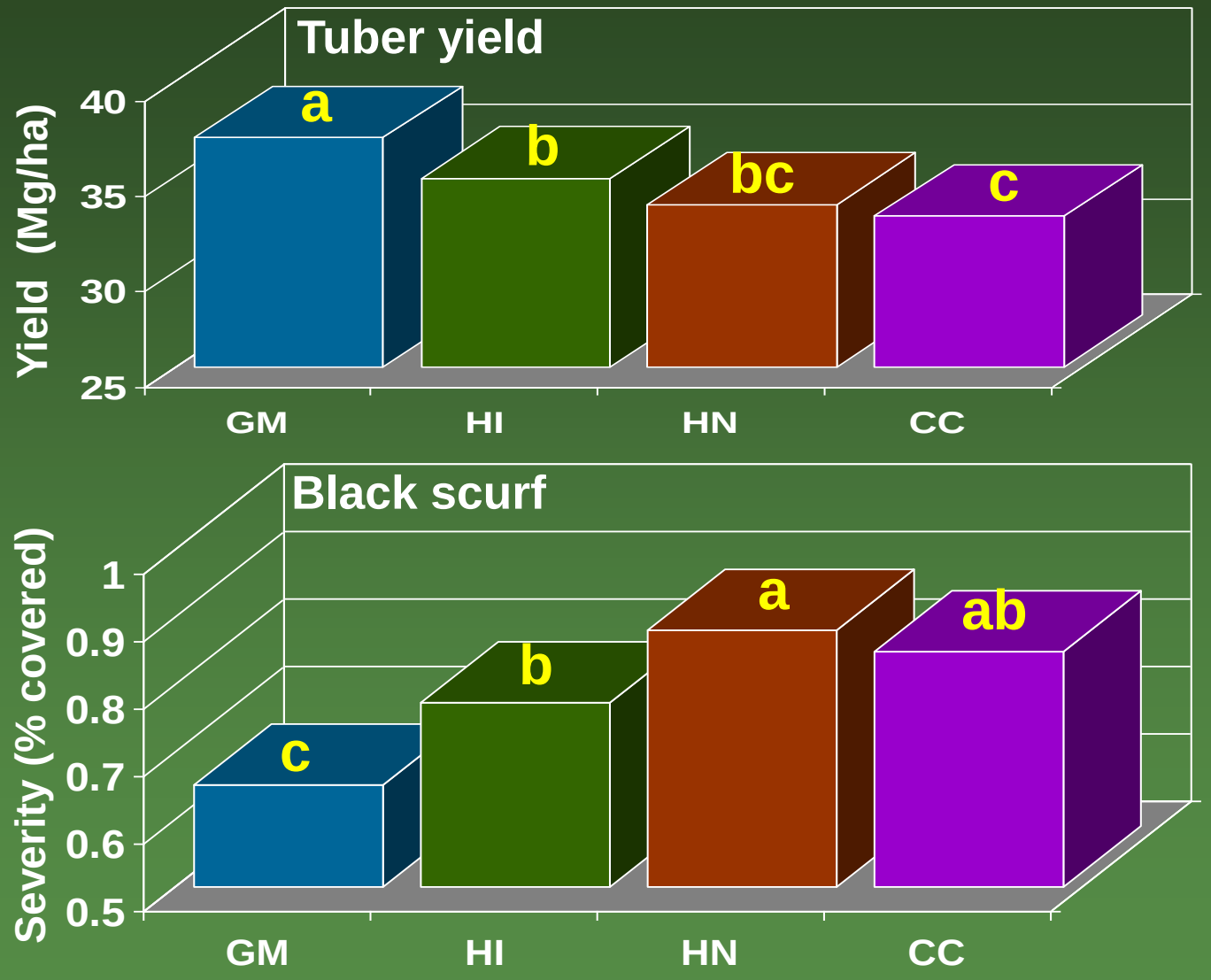
Crops:

- MUS - Mustard Blend
- SUD - Sudangrass
- RPS - Rapeseed
- SOY - Soybean (nonsuppressive control)
- BAR - Barley/clover (standard rotation control)

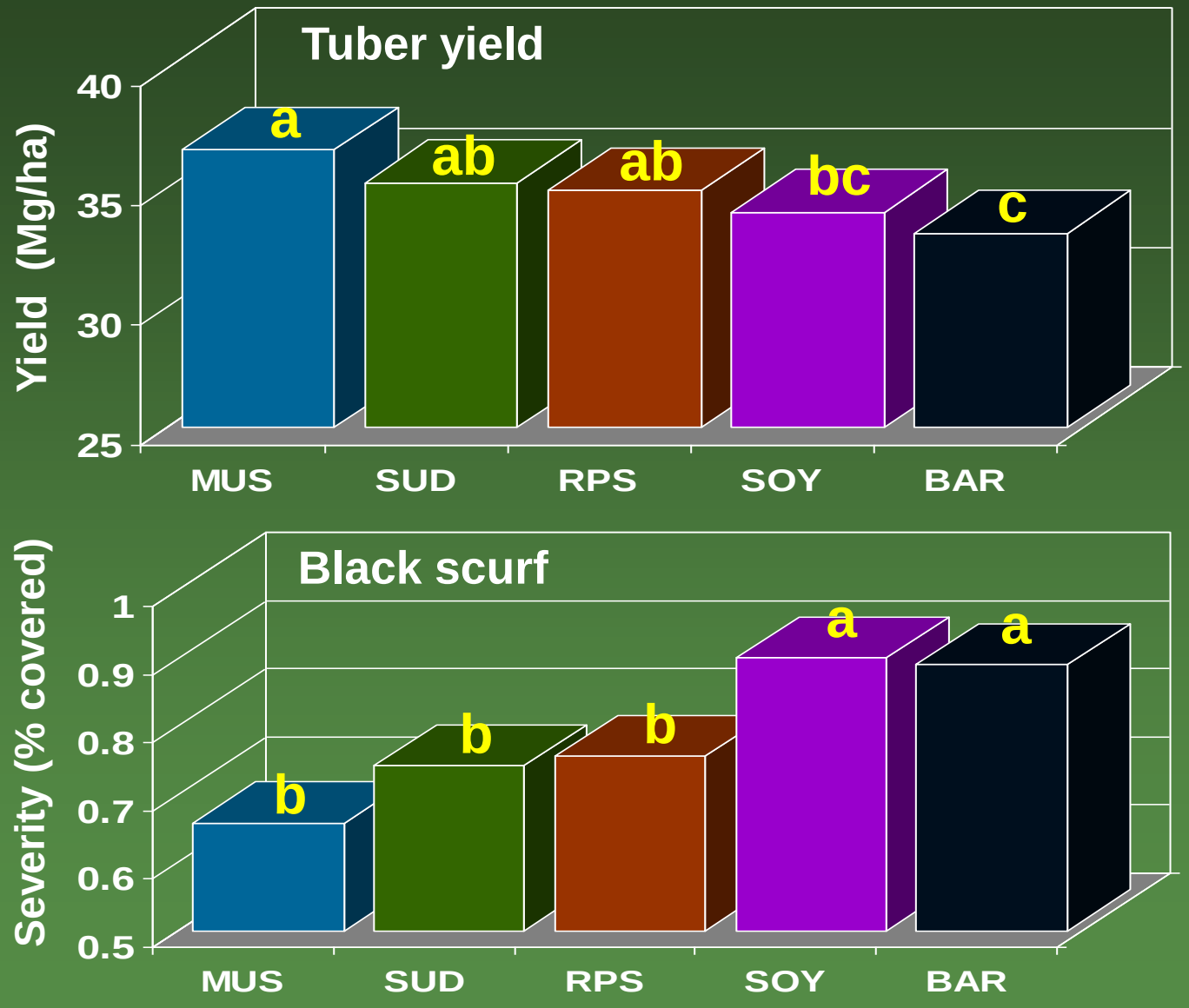
Management:

- GM - Green manure (incorporated green)
- CC - Cover crop (not incorporated)
- HI - Harvested (seed, oilseed), stubble incorporated
- HN - Harvested, stubble not incorporated

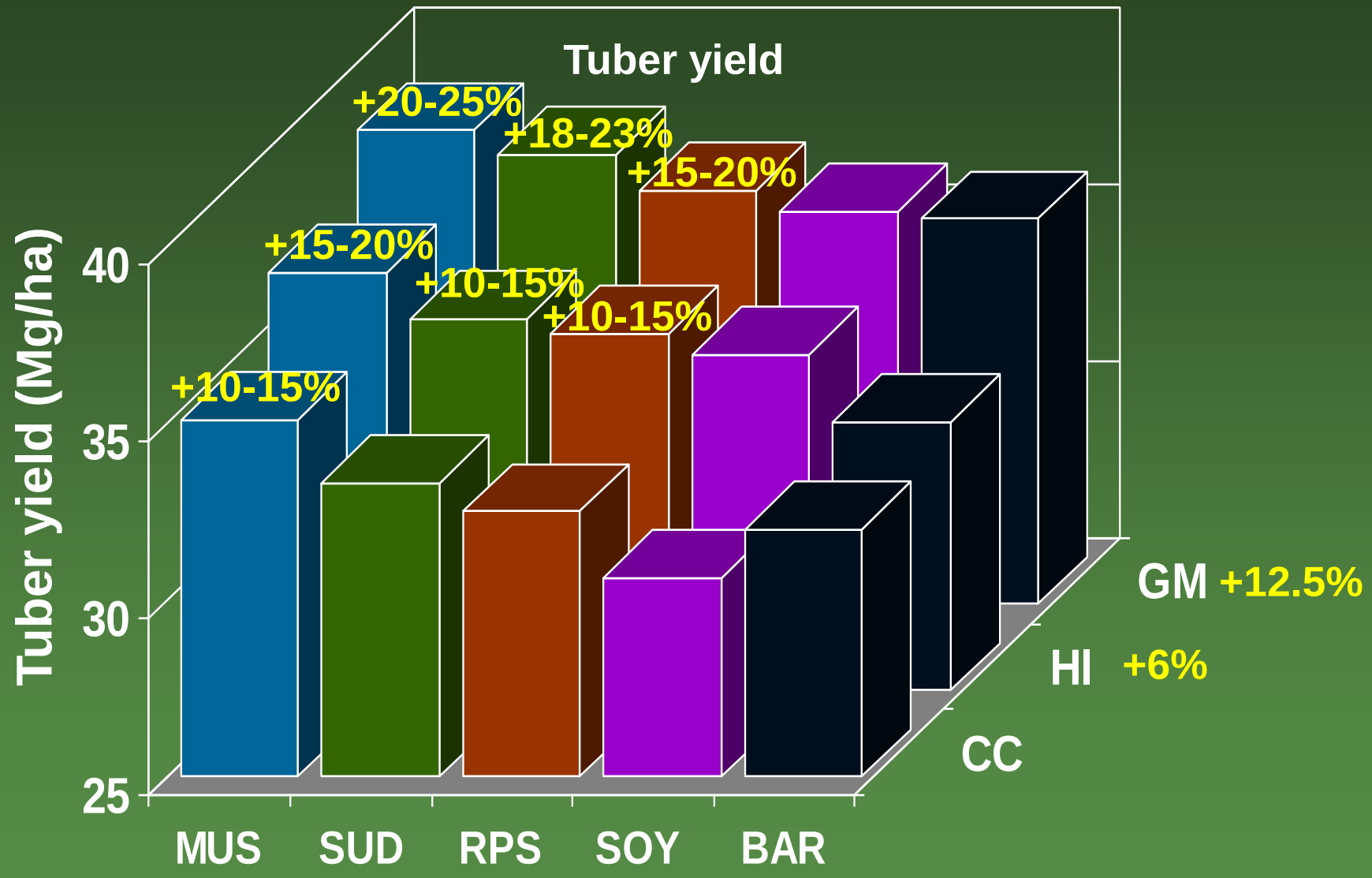
Effect of management practice on tuber yield and black scurf severity (2-yr avg)



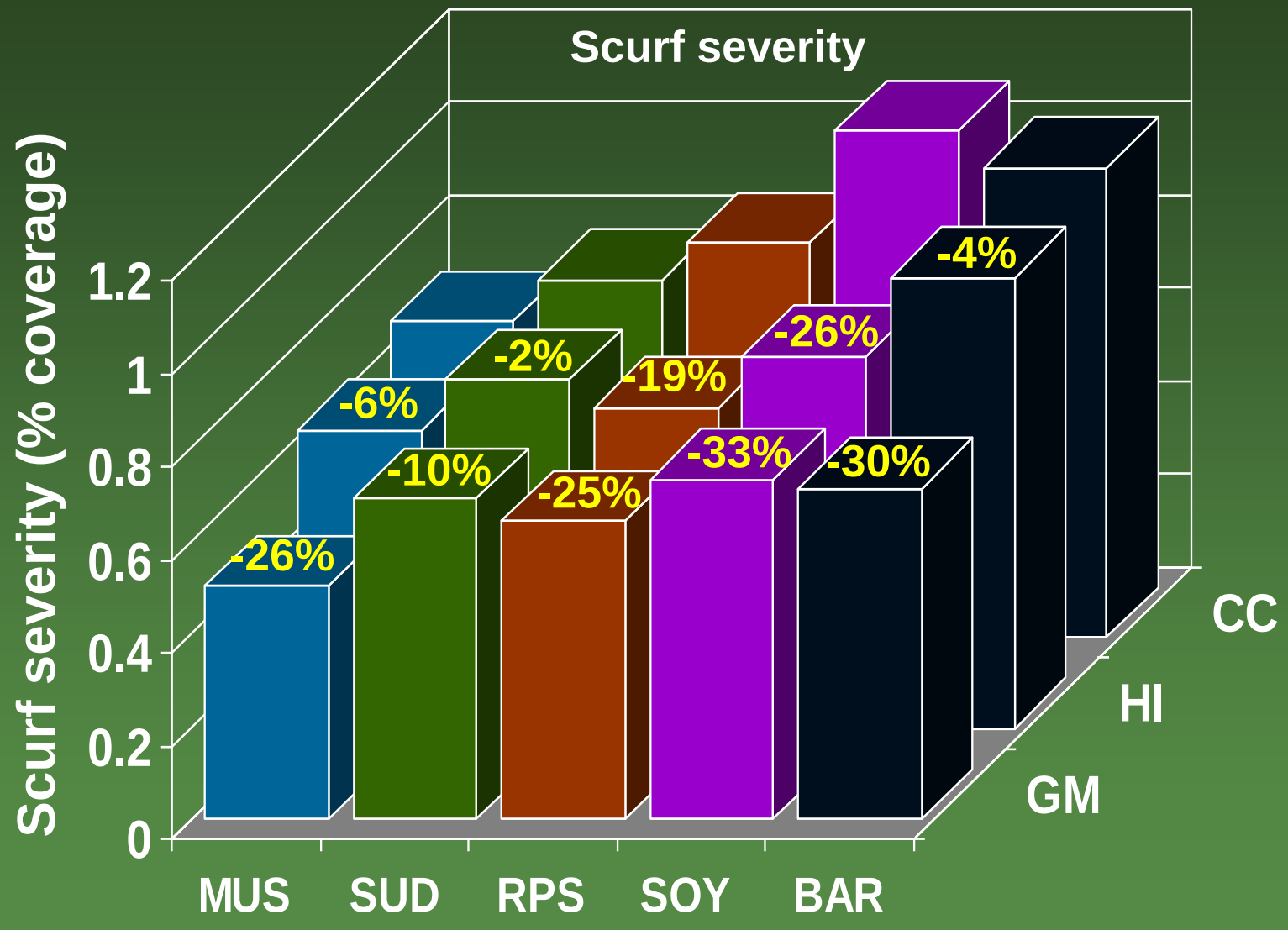
Effect of rotation crop on tuber yield and black scurf severity (2-yr avg)



Effect of rotation crop and management practice on total tuber yield (2-yr avg)



Effect of rotation crop and management practice on severity of black scurf (2-yr avg)



Economic Analyses

- Partial budgeting approach used to determine cost differences and their impact on net revenue
- Production costs adapted and updated from Enterprise budgets (Halloran) previously established by year and for total rotation (2-yr)
- Revenues determined from average actual and potential yields and average market prices for Maine
- Costs and revenues used to calculate gross and net revenue for each system over the course of the study

Effect of different crop rotations and management practices on net income return over 2-yr rotation (relative to barley harvested, not incorporated – HN)

Rotation crop	Crop Management Practice			
	GM	HI	HN	CC
	Net Income Change ($/acre) (including rotation and potato years)			
Mustard	259	349	316	8
Sudangrass	184	170	101	-193
Rapeseed	120	357	234	-238
Soybean	50	289	274	-426
Barley/Clover	18	-39	0	-313

Relative economics of 3-yr rotations – net income change for different crop rotations ($/acre/yr)

Rotation	Crop Management Practice	
	Rel to b/c-for	Rel to b/c 2-yr
	Net Income Change ($/acre/yr) (including rotation and potato years)	
Bar/clo-forage grass [PI]	-	-250
Bar/rg-Canola [SC]	+150	-100
Bar/rg-Canola (Comp) [SI]	+130	-120
Bar/rg-Mus/Rps [DS]	+40	-210
Bar/clo [SQ]	+250	-

Alternative rotation crops – Possibilities?

- Need for additional rotation crop with good economic return to make 3-4 yr rotations more economically viable
  - Previous research with soybean, green bean, sweet corn
    - can work in rotations, but soybeans, green beans resulted in greater disease issues, lower yields over time
  - Malting barley – better return, but stringent quality requirements
  - Pulse crops – dry beans (black beans), field peas, chickpeas, etc. – currently being researched
  - Others?
  - Market availability - All new or potential crops without previous history depend on availability of markets

CONCLUSIONS

- Incorporating management practices that promote soil health into potato cropping systems can improve soil physical, chemical, and biological properties, resulting in improved nutrition, enhanced yield, and disease suppression

- Soil health-building practices, such as use of crop rotations, cover crops and green manures, organic amendments, and conservation tillage, contribute to building active, diverse, and potentially disease-suppressive microbial communities.

- SI system, which included substantial compost amendments, had the greatest effects on soil health, including increases in total C and N, active C, microbial activity, water availability, CEC, and concentrations of P, K, Ca, and Mg, and reductions in bulk density, resulting in high yields, but only nominal disease reduction.

- DS system, which included disease-suppressive green manures, cover crops, and increased crop diversity, provided more modest improvements in soil health parameters, but also high yields and the greatest disease reduction, maintaining low disease levels throughout.

CONCLUSIONS

- **Brassica green manures can provide a positive economic return due to beneficial effects on potato disease and yield, and Brassica crops grown and harvested for seed can provide a greater economic return and still provide some benefits for disease reduction**

- **Rotation crops grown as green manures were more effective than when grown as cover crops for effects on tuber yield and disease reduction**

- **Use of soil health management practices and disease-suppressive crops can substantially reduce soilborne disease problems, but cannot completely eliminate them, may take time to develop, and should be used in conjunction with other approaches to achieve sustainable disease management**

CONCLUSIONS

- **Thus, based on our research (in Maine), best management of soilborne diseases, soil health, and sustainable production using cropping systems would include:**
  - **3-year rotation (or longer), with conservation tillage**
  - **Disease-suppressive rotation crop prior to potato**
    - ***Brassica* crop (such as Caliente Mustard Blend) GM**
    - **Sudangrass GM**
    - **ryegrass or small grain**
  - **Cover crop (winter rye or ryegrass) following rotation crop**
  - **Compost amendment may be used to improve organic matter, soil properties, water availability, and yield**
  - **After-potato year of rotation could include alternative cash crop or small grain**

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