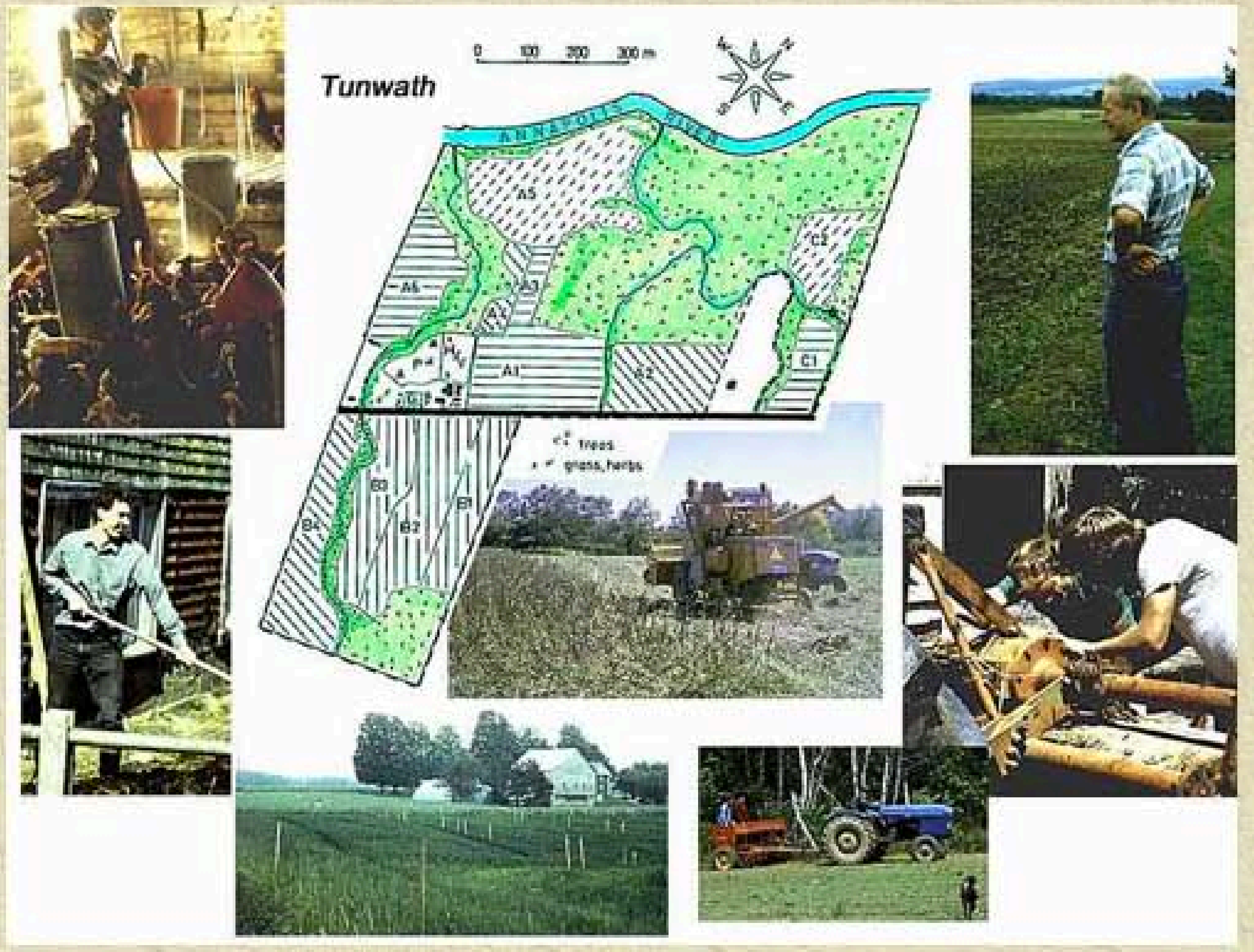
Tunwath Farm: an experiment in nitrogen self-sufficiency

This set of slides illustrates some of the on-farm research that was conducted between 1977 and 1986 on Tunwath Farm in the Annapolis Valley, Nova Scotia. In 1976, The farmers, Basil and Lilian Aldhouse had made a "cold turkey" conversion of their laying hen-grains farm from conventional to to organic management. Oat yields tumbled, apparently due to inadequate nitrogen. When I visited the farm in 1977, Basil asked me "why should my cereals be nitrogen deficient when I have legumes on a third of the land and I'm recycling manure from the barn?" I thought that was a good question and decided to pursue it. Finding the answer was very much a joint farmer-scientist endeavour that in the end, took seven years. A number of students joined the quest. We spent many hours conversing with Basil & Lilian, documenting the farm practices, helping with chores and sharing meals as well as the joys and frustrations of the journey.
- David P.



FABA BEAN: A PULSE (GRAIN LEGUME)

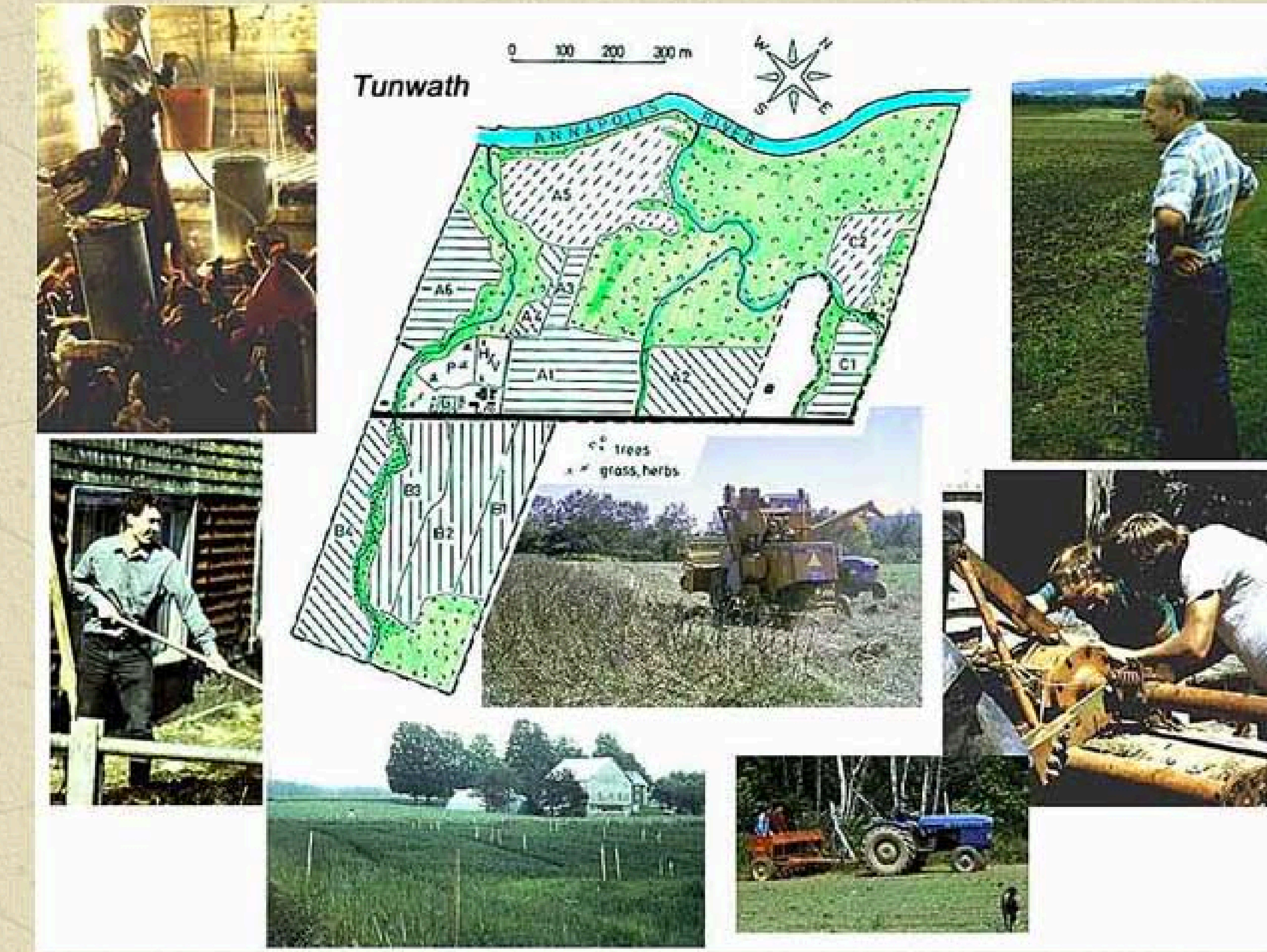
In 1977 I visited a number of farms in the Annapolis Velley where they had been growing fababeans successfully or were conducting trials with fababeans. While this pulse or "grain legume" had long been a major crop in Europe, it had not been grown much in North America. The N.S. Dept. of Agriculture was conducting fababean trials in collaboration with farmers and reported highly variable results. I surmised that poor performance might be related to poor nodulation, that in turn due to lack of the appropriate bacteria in the soil. (In such a case, the seeds can be inoculated with the appropriate rhizobia.) The photo at bottom right *above* illustrates a well nodulated plant.

The photos below show fababean at a site where there was no nodulation (left) and at a site where there was good nodulation (right).

One of the farms I visited was Tunwath Farm, near Lawrencetown, Annapolis Co. The farmers, Basil & Lilian Aldhouse, produced eggs from 2100 laying hens, a small number by industry standards. However, they wanted only as many birds as they could feed from crops grown on their own land, and that number was about 2100. "The barn should fit the land", Basil would say. In this regard they were unusual, as most commercial laying hen operations maintain many more birds and rely heavily or entirely on imported feed. In other respects, the farm was operated conventionally with routine use of fertilizers and herbicides, and pesticides as needed.

Basil was good at growing crops, receiving a prize in 1975 for the highest oat yield in the province. In 1976, he might have got a prize for the lowest yield! Basil and Lilian had become concerned about the health of their farm, e.g. Basil said he couldn't find earthworms any more. He had read a little about organic farming, and decided to make a "cold turkey" conversion: in 1976 he didn't apply any fertilizer or herbicide to his crops. He reasoned that with nitrogen-fixing legumes (fababeans, clover and alfalfa) on one-third of his land, there should be plenty of nitrogen going into the farm without fertilizers, and he figured he could control weeds adequately by mechanical means. However, his cereal yields dropped, and dramatically so for oats.

At the time, "organic farming" (also known as ecological farming, sustainable farming, biological husbandry) had little credibility within the mainstream. Extension agents had advised him against it and were not surprised when his oat yields tumbled, attributing it to lack of nitrogen. When I went to the farm in 1977 to look at his fababeans he told me about his experiment and asked me "why should the cereals be N deficient when I have legumes on 1/3 of land and I'm recycling the hen manure?

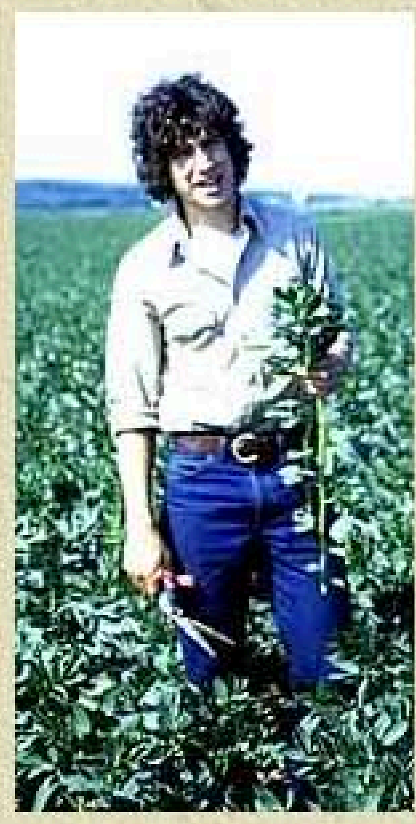


- 2100 laying hens x 30 ha crops (cereals, fababean, clover/alfalfa)
- Feed: 91 m.t. 17% protein
- With cereal and pulse yields of 3+ tonnes/ha, the farm was close to self sufficent in feed
- 1975: Highest oat yield in province - conventional management with use of fertlizers & herbicides
- 1976: Probably lowest oat yield - no use of fertilizers (except manure) & herbicides

Reduced yields were attributed N limitation: Farmer asks "Why should the cereals be N deficient with legumes on 1/3 of land?

Initially I thought it could be due to low levels of nitrogen fixation by his legumes and might be resolved by inoculation of seed with appropriate rhiozbia. So I would look at the legumes and do some measurements of nitrogen fixation. That was the first of a succession of hypotheses followed by observations or experiments that I and students working with me conducted in collaboration with Basil and Lilian in an attempt to understand and resolve the limitations to crop production on their farm.

Hypothesis I: Inputs via N_2 fixation are much lower than typical inputs from fertilizers.



Observations:

- Legumes were well nodulated.
- Measurements of N_2 fixation and rough calculations indicated total inputs of N to farm were equivalent to conventional fertilizer inputs.

Conclusion: *The limitation was NOT due to lack of N going into the farm.*

Hypothesis II: There are large losses of N from farm by leaching/runoff &/or ammonia from the roost, resulting in insufficent N for cereal crops

To test the hypothesis we measured stocks and flows of N on the farm:

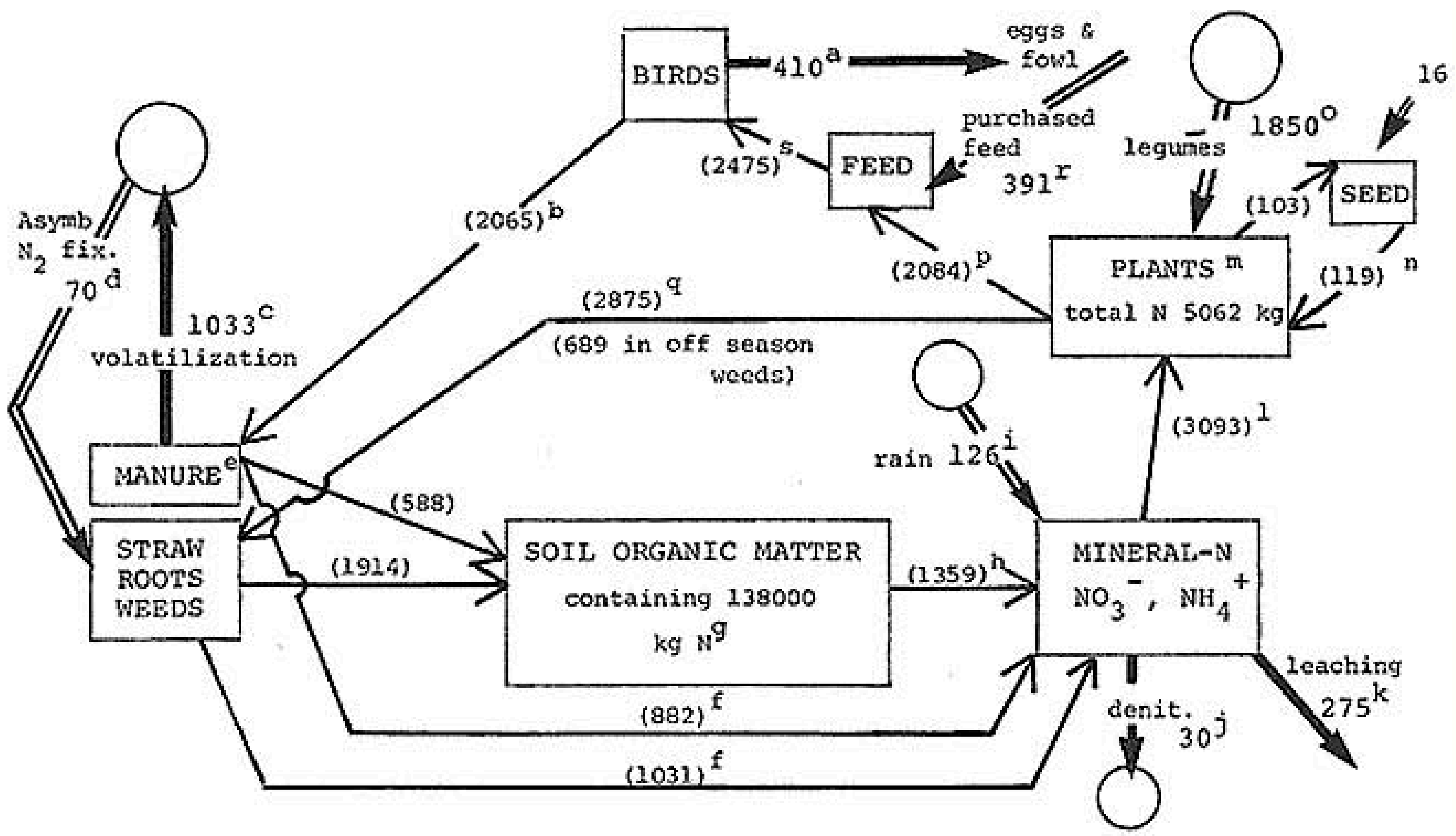


Fig. 2. Nitrogen budget for Farm B. Numbers in brackets are flows of N between compartments within the farm. Big arrows and accompanying numbers not in brackets are flows of N into and out of the farm. Circles represent the atmosphere. Units are kg N per farm per year. Calculations refer to 10 ha in beans, 7 in wheat, 7 in oats, 3 in clover and 3 fallow.

Observations

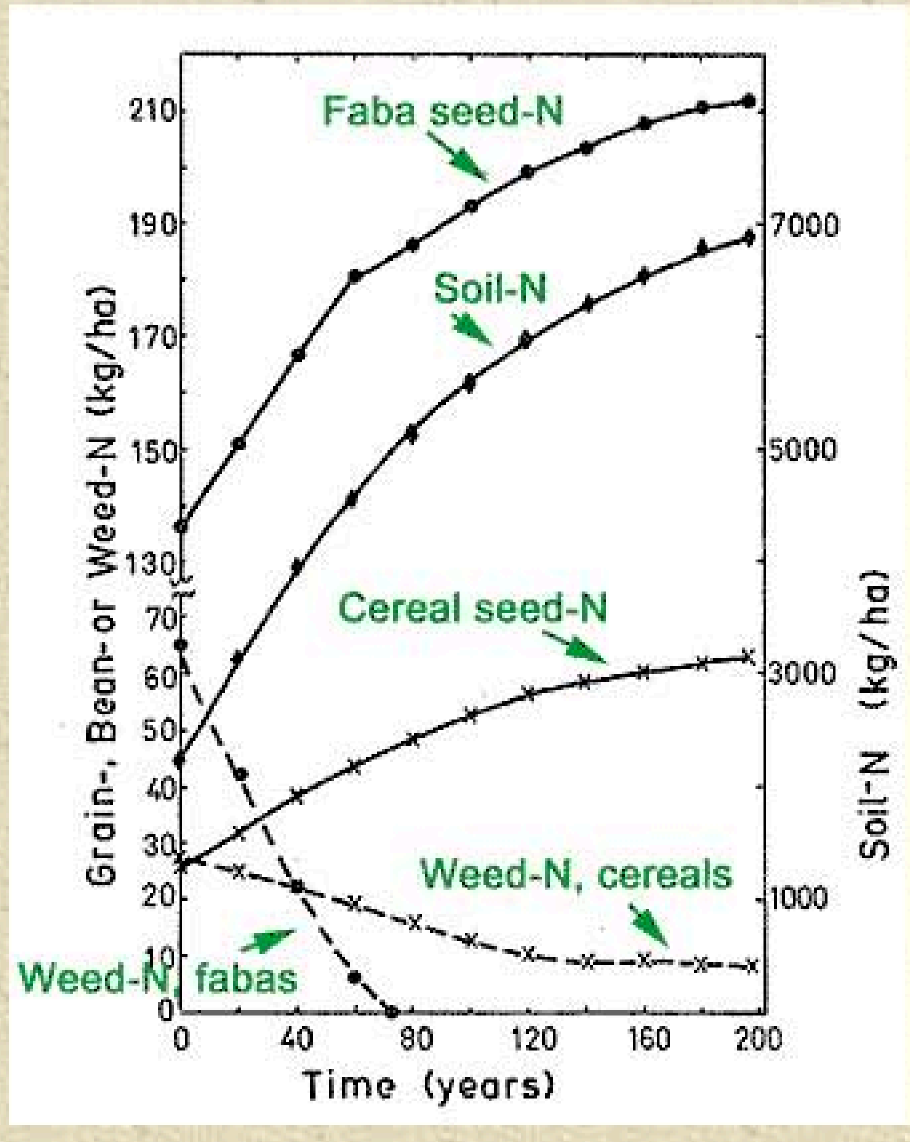
- There were only small losses of N via leaching and runoff.
- There were large losses of N from roost as ammonia.
- Even with these losses, there was still a lot of N going into the soil.
- There was more going into the soil than was leaving it.
- If the N mineralized from soil were equal to N inputs, the cereals would have adequate N for high yield.

Conclusion: *Soil Organic Matter (containing 5% N) was increasing at the expense of crop yield.*

Possible Strategy: OK, Good! As Soil Organic Matter (SOM) increases, the N mineralized will also increase so we wait for SOM to increase. ("Build up the organic matter" was a commonly cited strategy for increasing production in organic farming.)

Question: How long would it take for N mineralization and yields to reach acceptable levels?

Answer: From a model that incorporated our data: approximately 100 years!!!!!

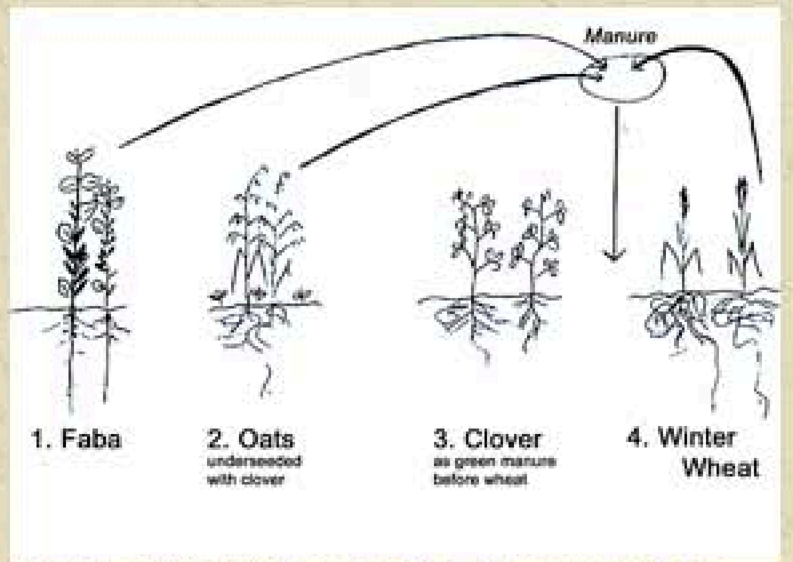


Waiting 100 years was not an option! So we came up with a different strategy.

Alternative Strategy: To Get more of the N cycling through the crops and less through humus and weeds:

- 1. **Institute a regular crop rotation.**
  to synchronize soil-crop N cycling, control weeds. (Crops were rotated, but on a somewhat ad-hoc basis according to needs & condition of the fields.)

- 2. **Put manure on crops and fields giving greatest response.**



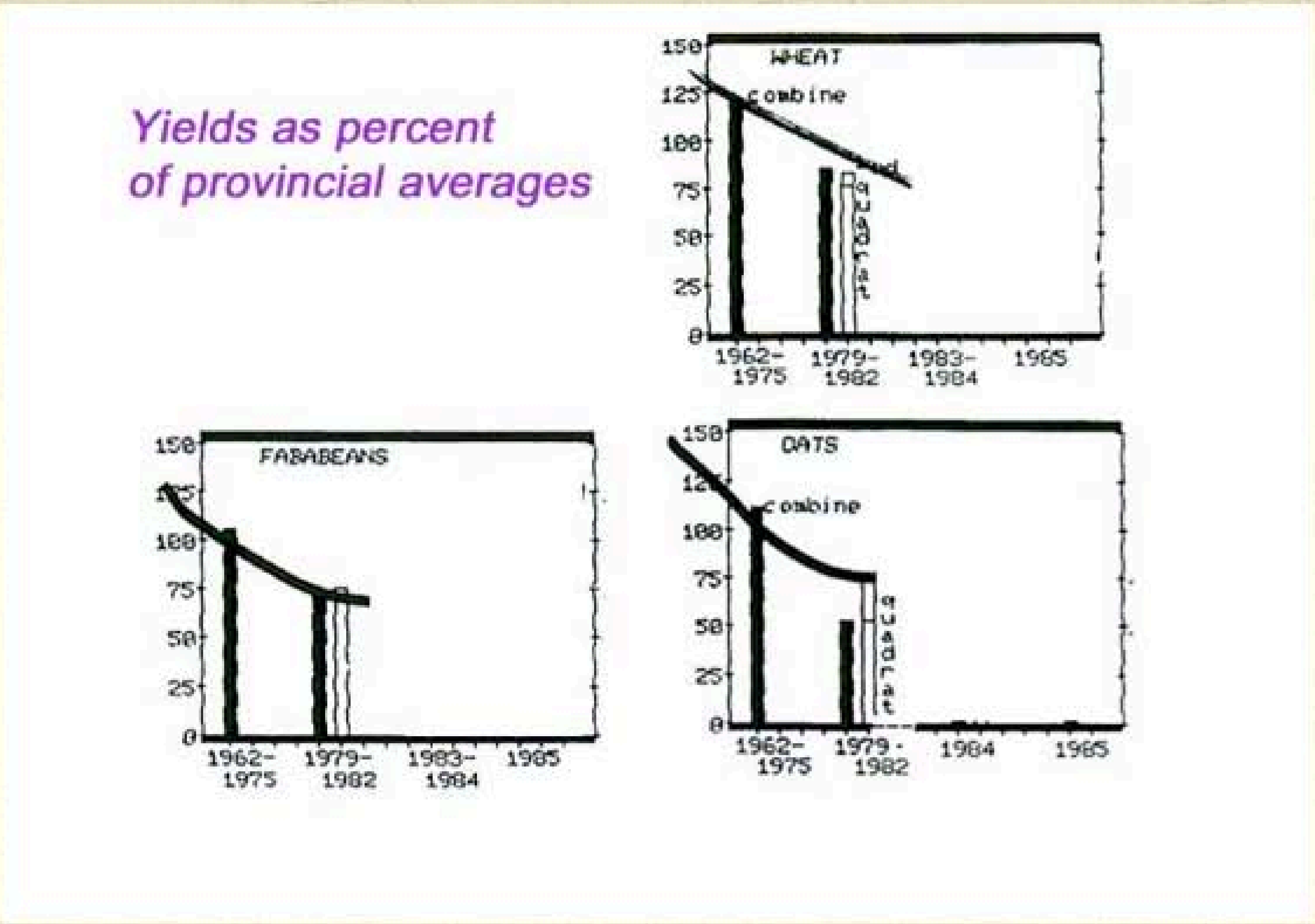
The crop rotation introduced in 1979. All manure went onto winter wheat.

- 3. **Correct any mineral deficiencies or imbalances** (Ca, Mg, K, P, S, trace elements).

- 4. **Use cultivars that are well adapted** to organic management and the local climatic & soil conditions.

- 5. **Manage weeds so that they complement the crop,** i.e. so that they can function as *self seeding cover crops* and provide habitat for natural enemies without signficantly reducing crop yields.
  We asked "What is the minimum weed control necessary?" We wanted to set back weeds so that they don't compete with the crop, but still allow them to exist beneath crops and on a field between successive crops.

This strategy was introduced in 1979. By 1982, we realized it wasn't working.

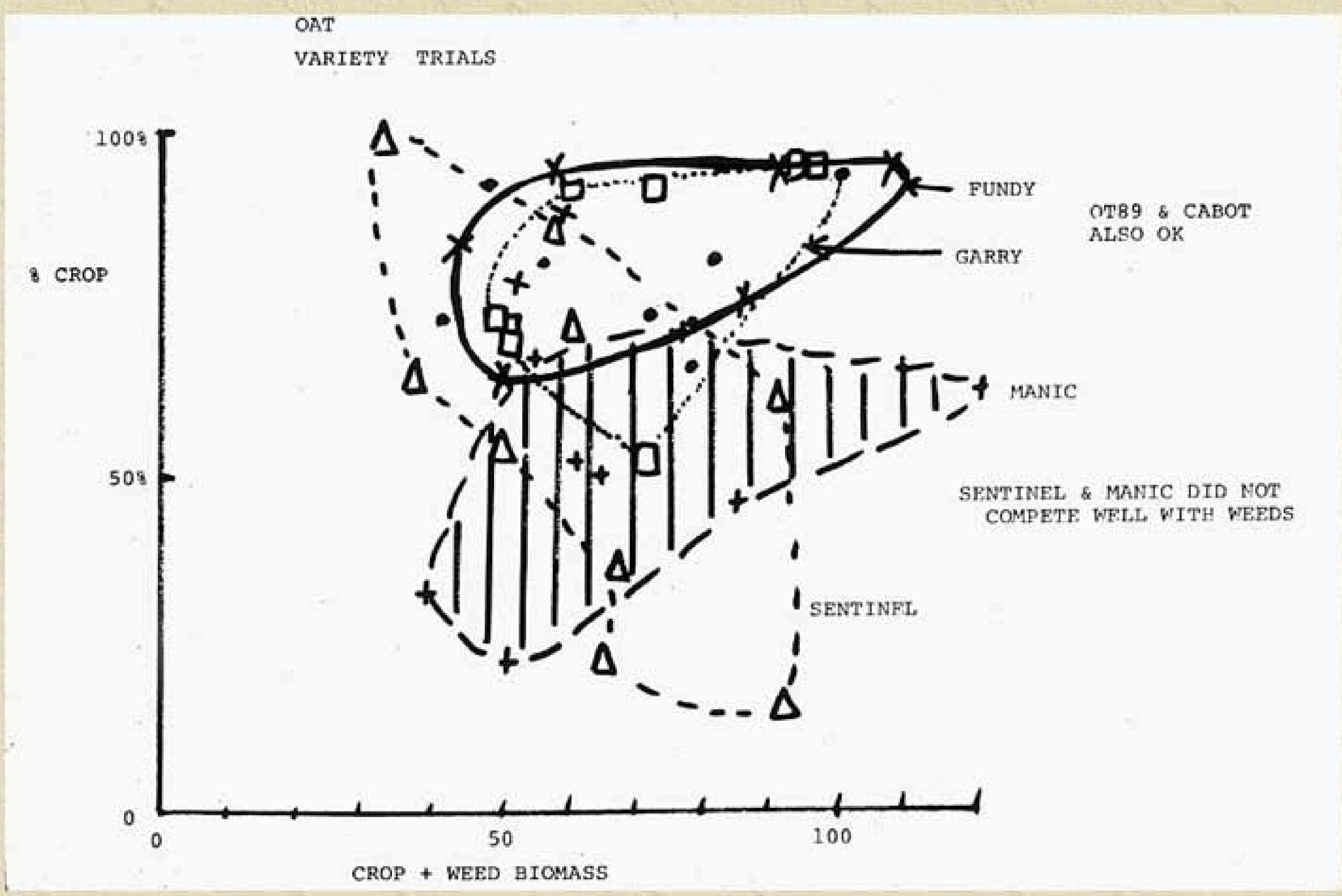


We were particularly puzzled by the low oat yields as oats are known traditionally as a "non-demanding crop" - that's why we put all manure on wheat, with none going to oats. As well, oats had been reported to produce well under organic management. So a set of experiments was superimposed on the farmer's regular operations to test hypotheses related to the low oat yields.

On-Farm Experiments

The posts mark the location of small plots superimposed on the farmer's crops. Winter wheat in the foreground, then oats, then fababeans, 1985.

Hypothesis: The oat variety (Garry) is non-competitive with weeds; other varieties could be more competitive.



Experiment: 3 traditional varieties (cultvars) and 3 modern culitvars were planted on each of 5 fields (3 reps at each site), and final crop and weed biomass determined.

Observations: The three tradional cultivars, including Garry (then in use on the farm) and one of the three modern culitivars competed well with weeds; two of the three modern culitvars did not.

Conclusion: The poor oat yields were not due to poor competitiveness with weeds.

Oats, mid June, 1981

The yellow flowers are those of wild radish which grew over the oats. Regardless, we were convinced that the difficulties we were having with oats were not due to weeds per se. Rather, we believed that some fertility factor restricted growth of oats and weeds took over.

Hypothesis: Low oat yields are due to mineral deficies or imbalances. ("Minerals" are nutrients other than nitrogen, e.g., phosphorous, calcium, potassium, sulfur, trace elements).

"Shotgun" experiment: 17 different combinations of various minerals and manure were applied to one or two plots per treatment on each of two oat fields.

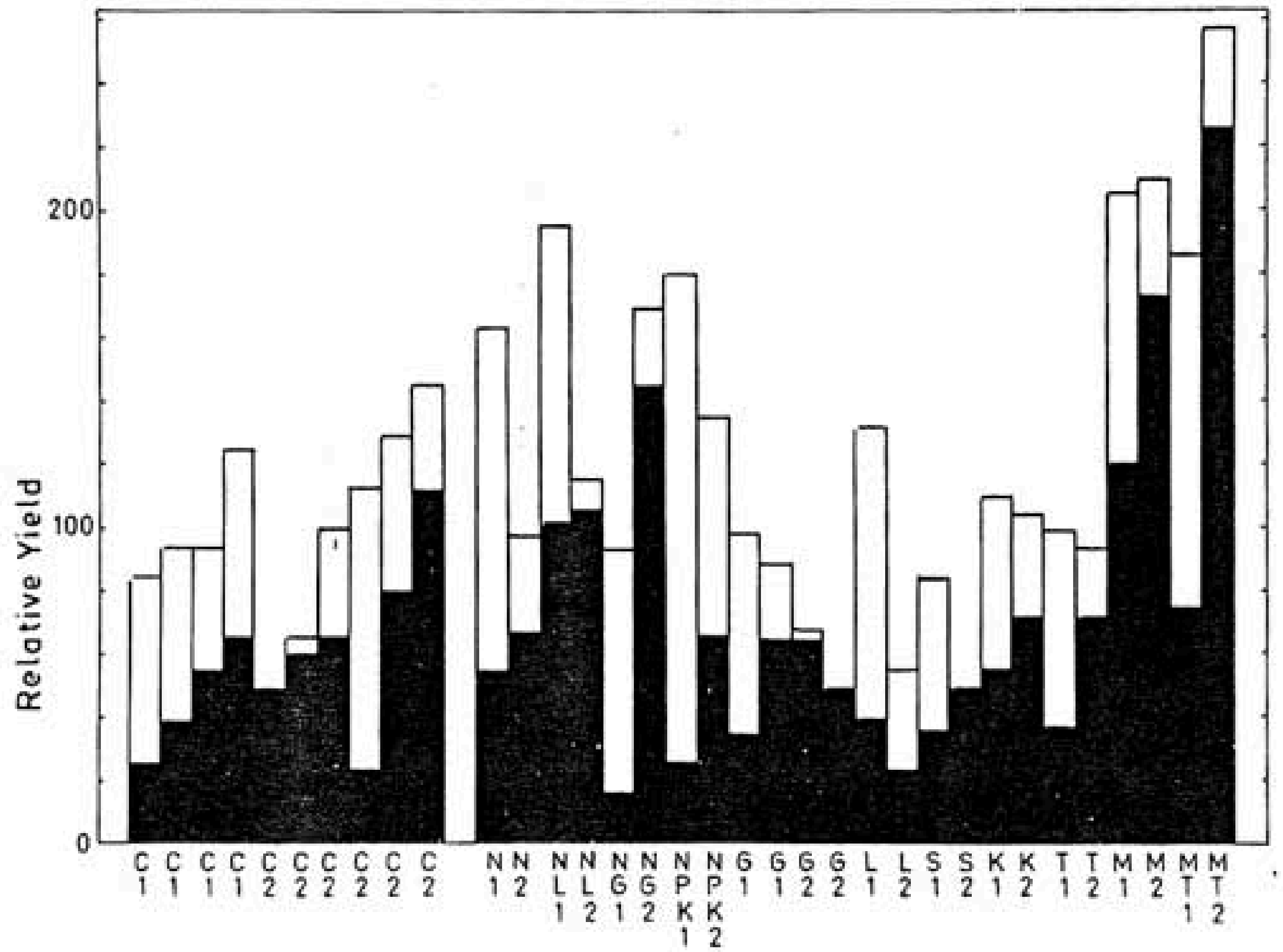


FIGURE 8 Yields of oats (shaded parts of bars) and weeds (open parts of bars) on individual plots receiving various fertilizer treatments. Numbers denote field (1=field A1, 2=field C1). Letters: C=control, N=nitrogen, L=dolomitic lime, G=gypsum, P=phosphorus, K=potassium, T=combined trace elements, M=manure. Values are: 100 × (observed yield/average control yield). Average control values for oats were 3123 kg on field A3 and 3655 kg on field C1. Data for plots in which trace elements (Zn, Cu, Mn, Fe, Bo, Mo) were applied individually are not shown.

Observations: We were looking for factors that would approximetely double the yields over controls.

- Treatments that included N had significant effects on total (crop + weed) yield but not on oats alone.
- Treatments that included manure had positive effects on both total (crop + weed) yield and on oats alone.
- Other treatments had little or no effect on yields.

Interpretation: Manure relieved **phytotoxic effects** in fields in which a lot of oat residues had been incorporated by stimulating microbial activity, & provided extra nitrogen. (We had other reasons for suspecting phytoxicity - next slide)

Strong evidence for phytotoxicty limiting oat yields came from the Oat Cultivar Experiment.

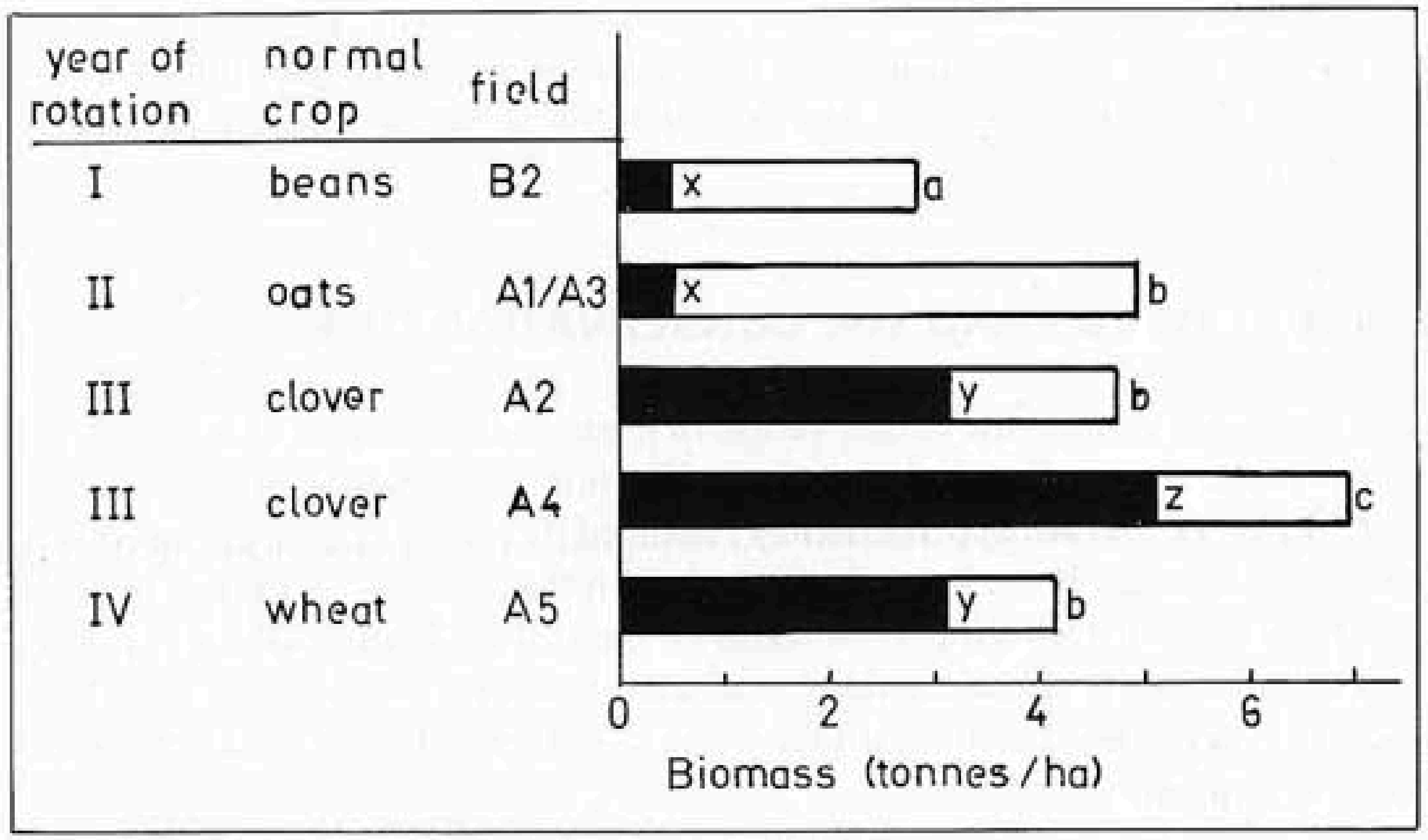


FIGURE 4 Total biomass (crop + weeds) and crop (shaded) biomass on oat cultivar test plots in 5 fields in 1982. Bars followed by different letters represent yields which differed significantly from each other as assessed by the rank sum test ($\alpha = 0.05$). On each field, six cultivars were planted, each cultivar in three 2×2m plots. The central 35×35cm were harvested at maturity. The low oat yields on field B2 and A1/A3 are indicative of phytotoxic effects of residues from the previous years' crops (wheat and beans respectively). The low total yield on field B2 is attributed to immobilization of N by wheat residues. Data from Patriquin *et al.* (1986).

In that experiment, oat biomass was very supressed, and more so than weed biomass, where the oats were planted in years 1 and II of the rotation, but not where they were planted in fields in years III and IV of the rotation.

In the rotation initiated in 1979 oats were being planted in year II, following fababeans (yr I).

We attributed the low yields to incorporation of large amounts of residues following winter wheat and fababeans. These residues consumed oxygen in the soil causing formation of fermentation products which were phytotoxic to the oats early in the season.

Weeds fared better because they germinate continuously and could respond when the residues were more decomposed and less phytotoxic.

Combining Fababeans in October

Fababeans are a long season crop (planted in May and harvested in October) and produce a lot of residue that is left behind when the grains are removed by combining. After combining, the farmer rotovated the residues into the soil. We surmised that as the residues are incorporated late in the year, there is not much decomposition over the winter. In the spring there would be very active decomposition and consumption of oxygen as the residues decompose, pockets in the soil go anaerobic and organic acids such as lactic acid accumulate for a period. When oats are planted in such soil, germination &/or early root growth is inhibited by the organic acids and oats get off to a poor start. Weeds keep on germinating and soon take over the crop.

Rotovating residues into the soil

Before he switched to organic management, Basil had used a mouldboard plough to cultivate his fields in the fall. He changed to rotovating in order to get better incorporation of residues into the soil so they would turn over and release their nutrients more quickly.

The rotovator was more effective at cutting up and mixing residues into the soil than the mouldboard plough (right) but it didn't achieve a critical benefit of mouldboard ploughing: a slight ridging (hilling) of the soil. Ridging is a benefit in heavier soils in cooler, moist climates as it results in better surface drainage and faster warming up of soil in the spring. We speculated that ridging the soil after cultivating might reduce the phytotoxicity problem.

Right: soil that has been mouldboard ploughed.

In the fall of 1983, Basil rigged up a toolbar with shovels as shown above and pulled that over the field after rotovating the fababean residues into the soil.

Field after rotovating fababean residues followed by ridging

Fall of 1983: Residues are well mixed into the soil and it is nicely ridged (hilled).

Field in the spring of 1984

Note the differences in colour between the hills and the troughs; the hills are well drained, the troughs retain mositure. At this stage, Basil harrowed the field to level the soil and cultivate (disrupt) weed seedlings, then seeded oats.

June, 1984

The oats are well up and ahead of the weeds!

Weeds are up too but remain below the oats

The oats got off to a good start and shaded the much more numerous weeds.

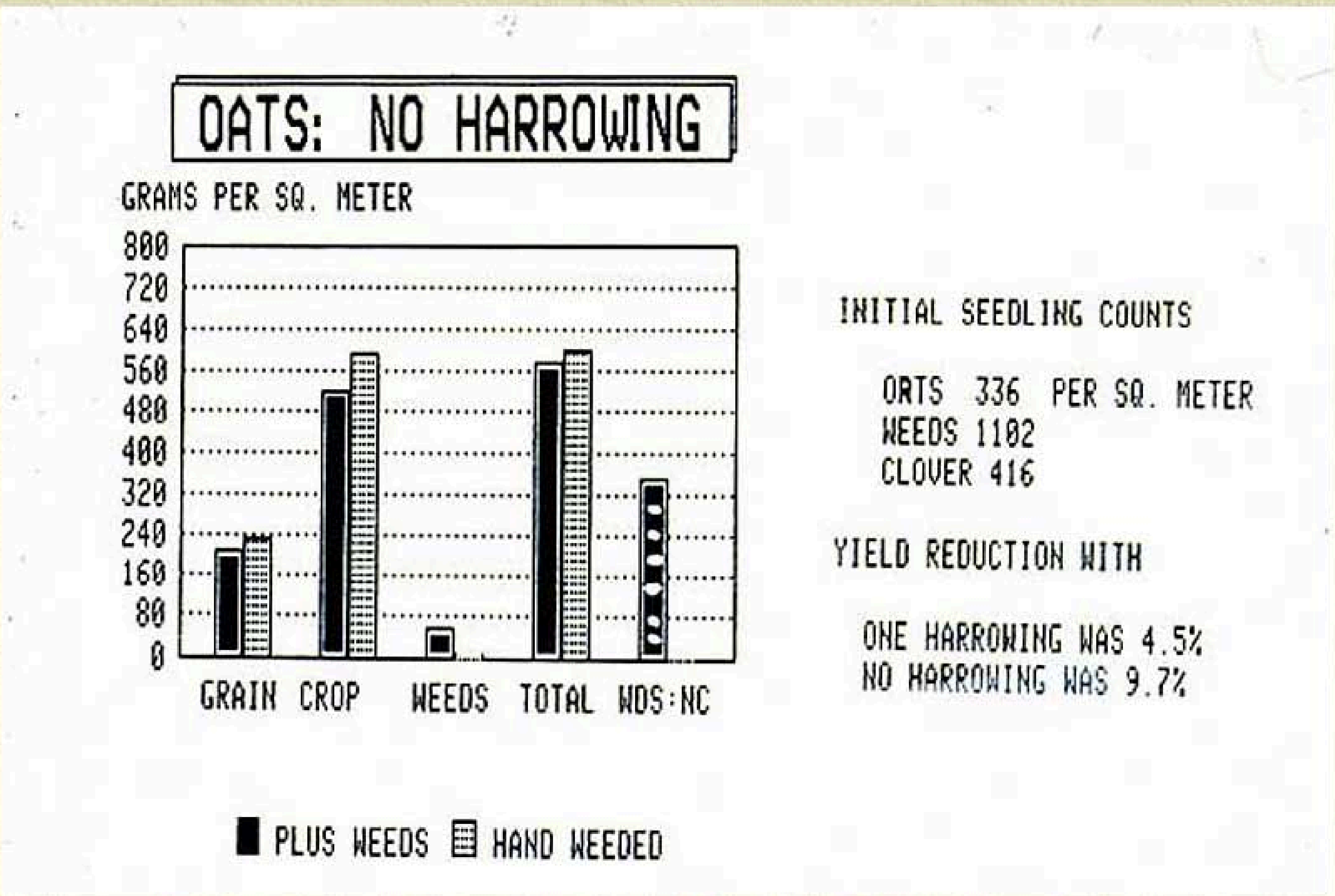
August 1984: The first really good crop of oats since 1975!

1985 Experiment

Effect of weeds on oats
& effect of oats on weeds

Control Plot (no weeding): weeds are present but were shaded by the faster growing oats and produced only a small biomass

Plot with no oats: Without the faster growing oats to shade them, weeds grew very large. The main weed is ragweed.



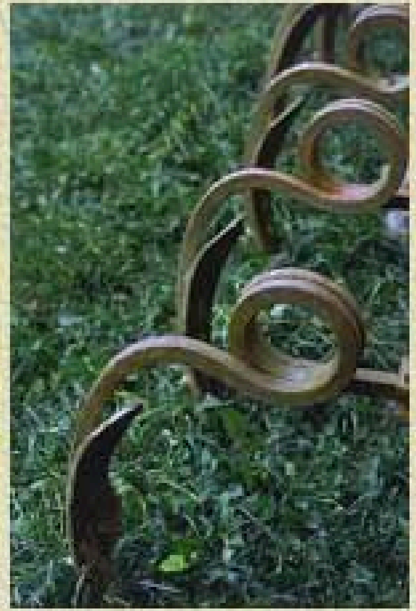
The usual practice for controlling weeds in oats was to harrow a field before seeding so that oats were seeded into a clean seedbed. Then they would be harrowed again after the oats were 7 to 10 cm high. At that point the oats are well rooted and recently germinated weeds are shallow rooted. Harrowing is like a light raking and pulls out the weeds but not the oats.

In this experiment, part of the field was not harrowed after seeding and part was harrowed once. Then three treatments were set up in 1x1 m plots (5 reps): (i) no additional action, (ii) repeated weeding with a hoe until canopy closure, (iii) oats removed. The bar chart shows the results for plots in the unharrowed strip. The oat yield was reduced by only 9.7% with no weeding. On the other hand, weed yield was reduced more than 6 fold by the crop (compare bar for WEEDS with WDS:NC (weeds in a plot with no oats).

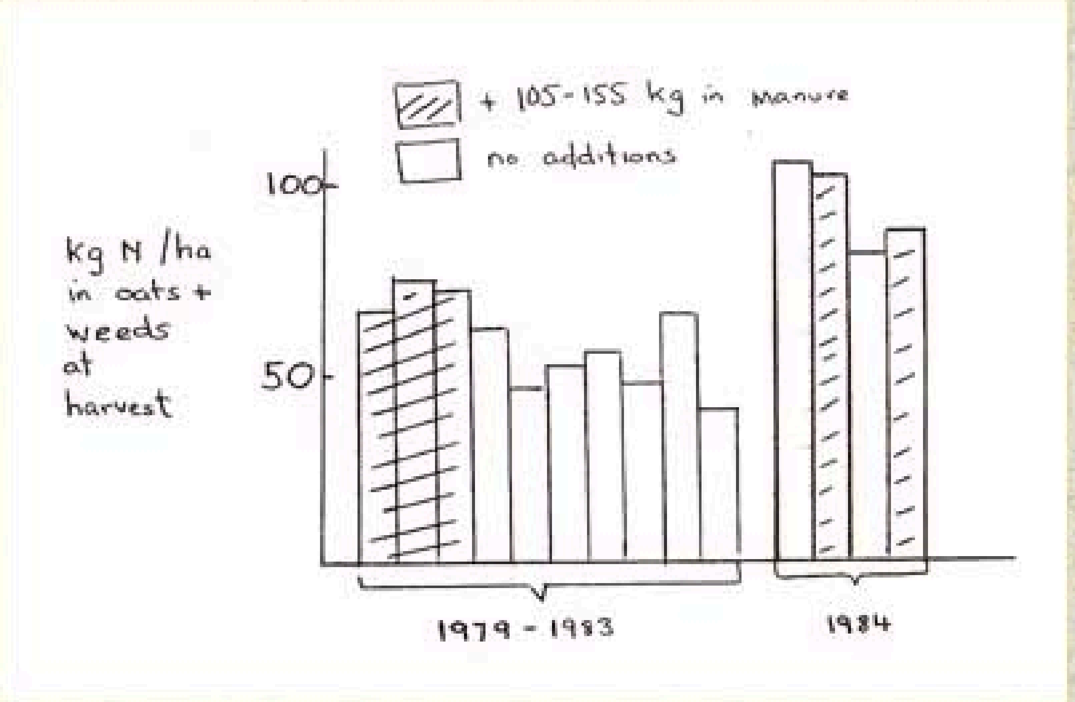
In the once harrowed section, the crop yield was reduced by 4.5% by weeds.

Conclusion: Oats were highly competitive with weeds under these conditions.

Before and after introduction of ridging

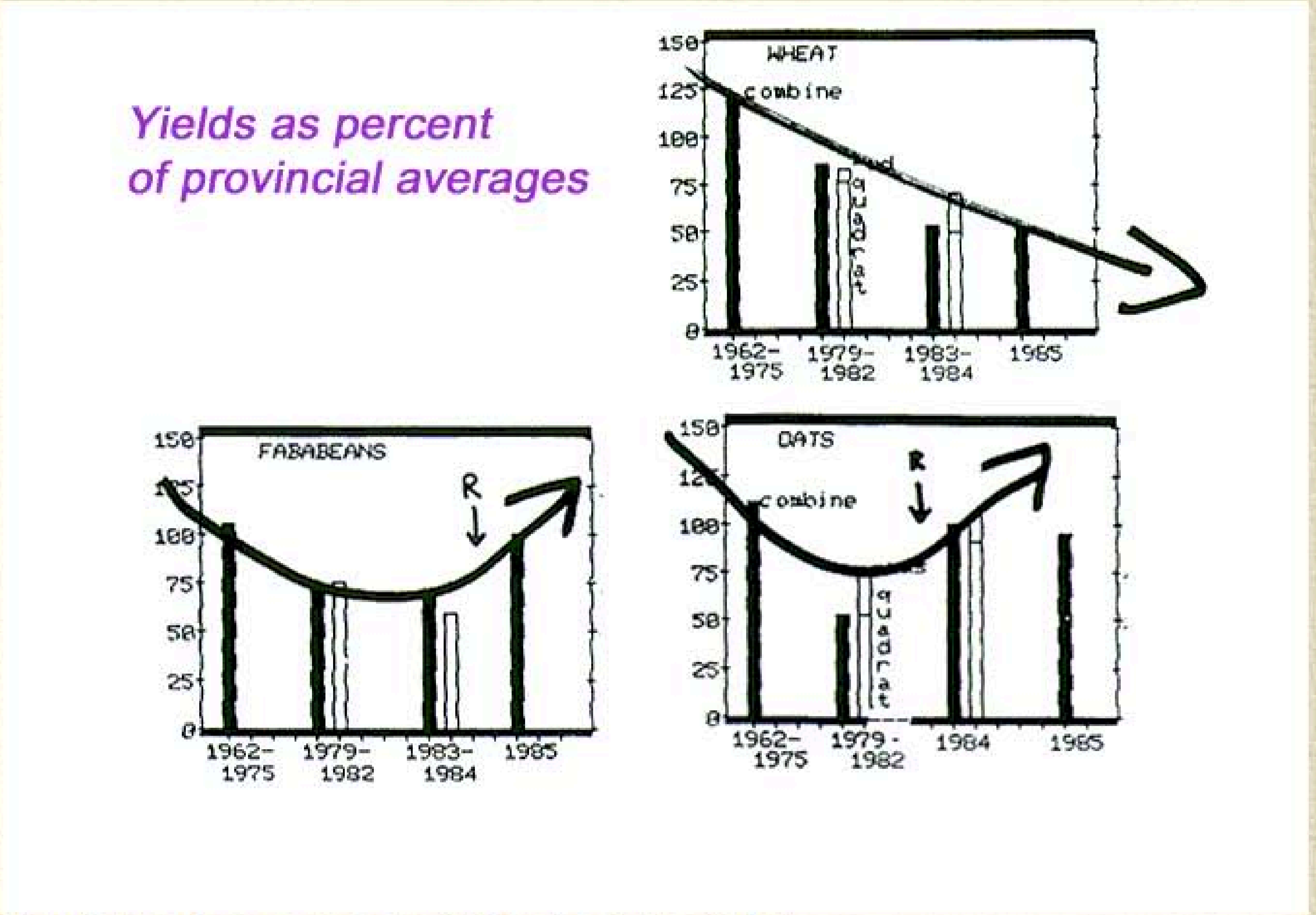


The change from the situation at left (weeds growing over oats & poor oat yield) and that at right (oats dominate over weeds, high oat yield) was entirely due to one operation: ridging the soil after rotovating fababean residues in the fall & prior to planting oats the next spring.



Oats from experimental treatments in a 1985 experiment: C= no addition, P= phosphorous, N= Nitrogen, P+N= Phosphorous + Nitrogen, Manure

After the change in tillage (fall of 1983), oat yields increased and there was no response to manure. This result validated the original strategy of applying all manure on wheat, none on oats.



Good Yields for Oats in 1984! Again in 1985!

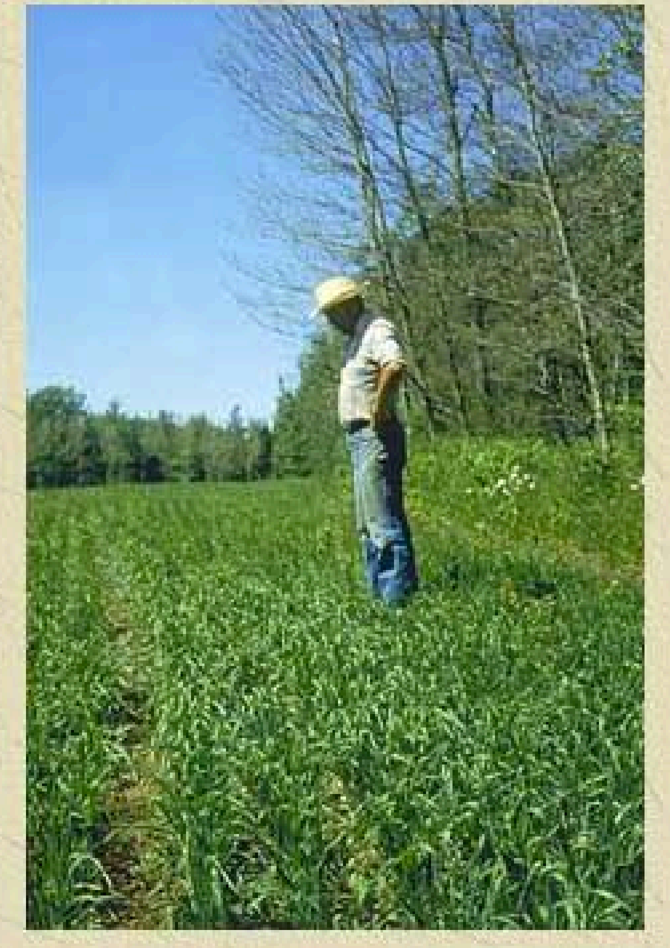
---> We resolved the yield issue for oats.

Fababeans: It turned out fababean yields had also been declining, likely also due to phytotoxicity. A change in tillage in 1984/5 (incorporating wheat residues by discing rather than rotovating) improved those yields in 1985.

Wheat: Yields continued to decline, but with more sets of experiments we identifed the cause. Clover is incorporated just before wheat is planted in year III and also generates phytotoxins. The solution: incorporate clover earlier in the year, and cultivate several times before planting wheat (in early Sept.) to set back difficult perennial weeds (mostly Canada thistle) as well as to aerate the soil and stimulate breakdown of residues and phytotoxins.

OVERALL

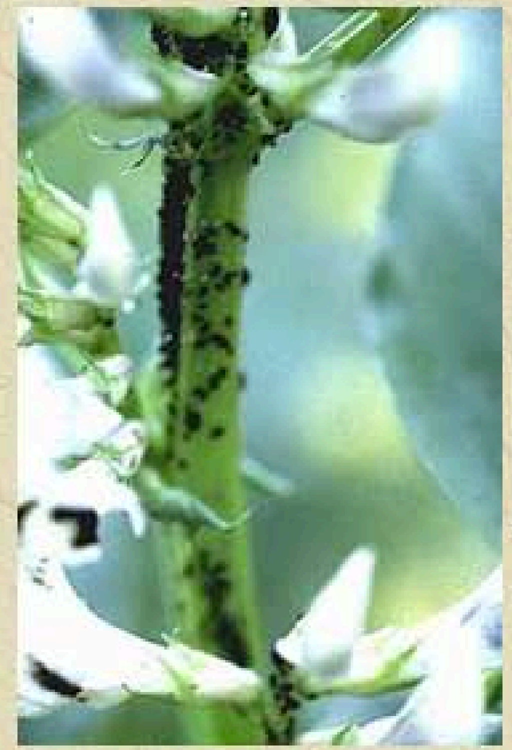
As inferred from the early observations, there was **ample nitrogen going into the farm via biological N2 fixation** to support high cereal yields.



It turned out the **yields were limited by a completely unanticipated factor** which was revealed in the course of scientific observations and experiments.

Basil Aldhouse died in early 1985, but had lived to see his organic experiment work. I and several students helped Lilian Aldhouse to keep the farm going over 1985 and 1986. We maintained the oat yield, improved fababean yield and identified the limitations in wheat.

We learned a lot about weeds and pests as well, and how they are affected by the way nitrogen is managed.



Pests became prominent in plots fertilized with nitrogen (as urea): at left, aphids on fababeans; above: rust (fungus disease) on wheat.

Lilian maintained the farm subsequently, but reduced the number of laying hens substantially. She died in 2009. Four of the dozen or so students who participated in my on-farm research at Tunwath and other farms today operate their own organic farms.
- David P.

Research on Tunwath Farm reported in scientific papers

Go to http://versicolor.ca/tunwath/Literature2.html for active links

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Patriquin, David. 2003. **Nutrient Management** *BC Organic Grower*, Summer 2003 **PDF**

Patriquin, David. 2003. **Building healthy soil from air and organic matter**. *EcoFarm & Garden* Winter 2003, pp 24-28. **PDF**

Patriquin, David. 2003. **Managing soils for effective pest control** *EcoFarm & Garden*: Spring 2003 **PDF**