Ceres Trust – Graduate Student Final Report

Innovative conservation tillage strategies in organic cropping systems for improving soil health and microbial activity

Peyton Ginakes, Applied Plant Science PhD student
Dr. Julie Grossman, Dept of Horticultural Sciences

Abstract

Strip tillage in combination with living mulches have gained traction in recent years due to possible environmental benefits and associated soil fertility enhancement, particularly for organic systems. This study examined two separate living mulch systems and the effect of reduced/strip-till management on cover crop nutrient contribution, soil quality, and crop yields. In one systems, a perennial kura clover living mulch was managed with four different tillage strategies for field corn production: no-till (NT), strip till (ST), zone till (ZT; a novel, PTO-driven rotary zone tiller), and double till (DT; ST and ZT). The other was a vegetable production system using winter annual cover crops, wherein a winter rye/hairy vetch mix (RV) and oat/field pea mix (OP) were either conventionally tilled (CT; full-width) or strip tilled (ST) before plastic mulch was laid and summer squash were directly seeded. In strip till systems, between-row cover crops were left to continue growing, indefinitely for kura clover and until legumes flowered for winter annuals. In both systems, cover crop biomass and carbon/nitrogen content were measured. In addition, soils were analyzed from in and between row areas for permanganate oxidizable carbon (POX-C), an assay indicative of soil quality and microbial activity, and crop yields were analyzed.

Objectives

Primary objectives of this project were to:

1) Assess perennial kura clover and two winter annual cover crop mix contributions to soil nutrient pool,
2) Quantify, and elucidate spatial distribution of, soil labile organic matter pools as affected by cover crop management, and
3) Evaluate effect of cover crops and associated reduced-till management methods on crop yield.

Perennial Kura Clover Living Mulch in Field Corn Production

Background

Zone tillage is a reduced till method where crop rows are tilled while living ground cover is maintained between rows. It is especially well-suited to living mulch systems, where perennial cover crops provide ground cover year-round. In conventional zone tilled systems, zones are created with herbicides. However, zones must be created mechanically in organic systems, and perceived yield reductions prevent organic growers from adopting zone tillage as widely as their conventional counterparts. Approaches to zone creation differ in the degree to which the living cover crop will compete with the cash crop. In this study, we evaluate crop productivity and soil biological responses to two zone tillage approaches in an organic field corn production system utilizing kura clover, a long-lived and winter-hardy perennial legume.

Materials and Methods

Plots are located in Rosemount, MN. Kura clover was established in the field used approx. 7 years ago, and is now well-established and robust (**Photo 1**). Soybean was grown in 2014, prior to the experimental year.

Plots were squared on 16 April 2015. Plots were randomly assigned to one of four treatment - no-till (NT), strip till (ST), zone till (ZT), and double till (DT) – and were replicated four times. Each plot consisted of six rows on 0.762 m centers. Rows were 9.144 m long, with 1.524 m on either end serving as a buffer and data being collected only from the two center rows.

All plots were fertilized with a drop spreader on 24 April. Only potash and phosphate were applied, at 134.502 kg ha^{-1} and 103.118 kg ha^{-1} respectively. The drop spreader was 0.6096 m wide and was applied over the center of 0.762 m row.

On 30 April, “pre-till” kura clover biomass samples were taken by compositing two 0.1 m^2 quadrats from both in-row and between-row areas for each plot (**Photo 2**). Samples were dried in a 35°C oven for a minimum of 48 hours, and then were weighed, dried, ground to 1 mm, and analyzed for carbon (C) and nitrogen (N) content. The same was done for “mid-season” and “harvest” kura clover biomass cuts, taken on 20 August and 2 October, respectively. At the two latter sampling dates, biomass was separated into kura clover and weed samples, and analyzed independently.

Also on 30 April, “pre-till” soil samples were collecting by compositing ten soil cores from the top 15.24 cm of soil from both in-row and between-row locations per plot. Composites were divided into two; one subset was kept field-moist at 4°C, sieved to 2 mm, and used in two soil assays, while the other was dried at 35°C, sieved to 2 mm, and used for three soil assays. The same was done for “post-till” and “harvest” soils, collected on 19 May and 9 October, respectively.

Field moist soil was used to measure potentially mineralizable N (PMN) and microbial biomass (MB). A 7-day anaerobic incubation was used to measure PMN. Soils were divided into two. One was kept at 4°C, while the other was waterlogged and incubated at 37°C for 7 days. After the incubation, both samples were extracted with 1M KCl and frozen. The difference between incubated and non-incubated samples is representative of organic nitrogen that is deemed “mineralizable”. These samples are awaiting analysis on a Shimadzu TOC-L Analyzer fitted with a nitrogen unit. Similarly, MB was measured using a simulated chloroform slurry extraction method, where one subsample was extracted with 0.5M K_2SO_4, while another was shaken with 0.5M K_2SO_4 and 0.5 mL $CHCl_3$ for 4 hours at 240 rpm. Chloroform lyses microbial cells, enabling their extraction; the difference between chloroform fumigated and unfumigated samples are assumed to be representative of microbial biomass. Extractions were collected and “fumigated” samples were bubbled for 30 minutes in order to evaporate chloroform. These samples are also awaiting C and N analysis on a Shimadzu TOC-L Analyzer fitted with a nitrogen unit.

Soils that were dried after collection were used for three soils assays. One is total carbon and nitrogen analysis (TOC/TN), which was measured on an Elementar Vario MAX CHN elemental analyzer. These data have been collected, but have yet to be statistically analyzed. The second is permanganate oxidizable carbon (POX-C), wherein soils are briefly introduced to potassium permanganate, a strong oxidizing chemical that loses its deep purple color upon oxidation, in order to assess the amount of labile organic matter available for microbial metabolism. After being shaken with KMnO4 for two minutes and settled for 10, the supernatant is measured with a spectrophotometer at 540 nm to measure color change. Finally, soils are being measured for light-fraction particulate organic matter (LF POM). This assay separates the physically distinct fraction of labile organic matter in soil through density fractionation: soil is combined with sodium polytungstate, a high density liquid (1.6 g/cm^3), and the organic matter that floats is then separated, dried, ball ground, and measured on an Elementar Pyrocube for C and N analysis. This assay is ongoing.

Corn was planted 5 May, and in-row areas were manually weeded bi-weekly throughout the season. Corn was harvested by compositing two 3.048 m rows of stover. Ears with any grain were removed for grain analysis (not yet performed). Immature ears were left with stover. Stover was chipped, subsampled, dried at 35 °C, ground to 1 mm, and analyzed for C and N on an Elementar Vario MAX.

Data were preliminarily analyzed with analysis of variance ANOVA using SAS (Cary, NC). Global effects were examined using PROC GLM, and, if significant, post-hoc means separation (Tukey's HSD) was performed.

Cover Crop Results & Discussion

Preliminary results show that kura clover biomass was greater between-row than in-row before spring tillage. On average, between-row areas contained 16.989 g 0.1 m^{-2} kura clover dry matter, compared to 1.869 g 0.1 m^{-2} in-row (**Fig 1**). While it appears there was a treatment effect, this difference (ns) was likely due to differences among blocks ($P \leq 0.0275$). However, carbon concentration in kura clover was greater in-row, with an average of 41.78 %C, than between-row (40.09 %C; $P \leq 0.0003$; **Fig 2**). Nitrogen concentration of kura clover was not affected by treatment or location (**Fig 3**). Upon closer examination, the C:N ratio of clover was greater in-row ($P \leq 0.026$; **Fig 4**). This indicates that the clover was of better quality where was left to grow between-row, which may be due at least in part to its perennial aboveground growth. Because rows are permanent in this system, it is possible that in-row kura clover put more photosynthates belowground after annual disturbance, as is its nature during its establishment period. Regardless, kura clover did not contribute significantly to nitrogen input for the corn crop as was expected. This likely led to abnormally stunted corn growth and eventually yields.

Soil Results & Discussion

POX-C was examined at three times over the growing season: immediately before spring tillage, 19 days after tillage, and at corn harvest. POX-C was greater between-row (687.04 mg C kg soil^{-1}) compared to in-row (634.74 mg C kg soil^{-1}) at the pre-tillage soil sampling ($P \leq 0.21$; **Fig 5**). This difference may be due to a combined influence of repeated tillage events in-row over the course of 7-8 years, and the perennial nature of belowground kura clover inputs between-row. There was, however, no tillage treatment effect. Within post-tillage and harvest soil time points, neither tillage treatment nor soil location had an effect on POX-C.

When time points were all analyzed together, several effects emerged. Overall, POX-C pools were greater between-row than in-row ($P \leq 0.0049$), and there was more POX-C overall before tillage than after ($P \leq 0.0032$; **Fig 6**).

Corn yield was very low; most plants did not produce grain, so stover was collected. There was no treatment effect on yield (**Fig 7**).

Moving Forward

The experiment will be duplicated in 2016, likely in the same design and location as in 2015 so as to capture accrued tillage effects on soil quality. One planned amendment for the upcoming year will be to have a small section of the plot, separate from where soil data are collected, that will be fertilized. In 2015, organic nitrogen fertilizer was not used because it was expected to interfere with soil nitrogen assays. As a result, corn yield was extremely low. Aside from this, data collected and laboratory analyses are expected to be the same.

Winter Annual Cover Crops in Vegetable Production

Background

Organic vegetable growers in the Upper Midwest are restricted by the short summer growing season. Moreover, the inability of winter annual legumes to reach full maturity by the time of vegetable planting makes it difficult for growers to meet the National Organic Program's instruction to utilize cover crops to enhance soil fertility. Since legume cover crops are at their highest N concentration at flowering, organic growers often get less of a nitrogen credit than is fully possible from leguminous covers. This study seeks to increase the N contribution of legume cover crops, and overall labile soil organic matter pools, through the use of an innovative adaptation of strip tillage. By leaving living winter annual cover crops to remain growing between vegetable crop rows until flowering, growers may gain more cover crop N input. In this study, we evaluate the effect of varying cover crop management strategies, using conventional tillage and strip tillage, on soil biological responses, nitrogen cycling, and crop yield in an organic yellow crookneck squash system under both rye+vetch and oat+pea bicultures.

Materials and Methods

Plots in 2015 were located in a certified organic field on the MN Research & Outreach St. Paul Station. Rye+vetch and red clover were fall seeded on 8 September 2014. However, the cold winter and lack of snow cover resulted in exceedingly low winter survival of legumes. On 16 April 2015, the field was rototilled, re-randomized, and spring seeded on 17 April. Due to timing, red clover as a treatment was disregarded and in its place oat+pea was used. Therefore, cover crop treatments included oat+pea treatment and rye+vetch. Oat and field pea were seeded at 45.9549 and 100.03597 kg ha^{-1}, respectively. Winter rye and hairy vetch were seeded at 51.27894 and 16.1122 kg ha^{-1} respectively. This was done using a seed drill set to 0.1778 cm row spacing. Within each cover crop plot, both a conventional till and strip till treatment was used. As a result, each subplot consisted of three rows on 2.4384 m spacings and 6.858 m long. In conventional till plots, the entire area was terminated before bed preparation, resulting in bare ground for approx. 0.9144 m between crop rows (**Photo 3**). In strip till plots, only the center 1.524 m were terminated at spring planting; the between-row area was left to continue growing until legumes reached flowering, at which point they were assumed to have their highest N concentration (**Photo 4**).

Entire conventional till subplots and the approx. 1.524 m center of strip till plots were flail mowed and rototilled on 16 June. 10 days later on 26 June, plots were rototilled again to ensure a fine seedbed, and a bed prep/mulch laying unit (1721-D bed prepper and 1723 mulch layer from Buckeye Tractor) was used to raise row beds and lay black plastic mulch. Drip irrigation was also installed under the plastic mulch, although use throughout the season was negligible. No fertilizer, compost, or manure was applied in this system; cover crops were the sole source of nutrient input.

Due to severe herbivory problems, the original crops that were planted on 26 June (eggplant) were removed, and organic yellow crookneck summer squash were direct seeded in their places on 19 July. Harvest was taken three times per week from the middle row, from 3 September to 2 October. Squash were separated into marketable and "cull", counted, and weighed (**Photo 5**).

Cover crop samples were taken from in-row and between-row on 15 June by compositing two 0.1 m^2 quadrats and separating biomass into cover crop grass (oat or rye), cover crop legume (pea or vetch), and weeds. Samples were also taken on 15 July from strip till between-row areas in the same manner. These were processed and analyzed in the same way as kura clover, above.

Soils were collected at four times over the growing season: 15 June ("pre-till"), 25 June ("post-till"), 25 July ("mid-season"), and 23 October ("harvest"). This was done by compositing 8 soil samples from both in-row and between-row areas, and processing and analyzing the same way as outlined in the kura clover project.

Data were preliminarily analyzed with analysis of variance ANOVA using SAS (Cary, NC). Global effects were examined using PROC GLM, and, if significant, post-hoc means separation (Tukey's HSD) was performed.

Cover Crop Results & Discussion

Cover crops performed inconsistently, likely due to spring seeding and inconsistent termination of fall-seeded cover crops – particularly winter rye. There was no significant difference between the nitrogen concentration of biomass of field pea and hairy vetch (**Fig 8**). Due to very high variability among plots, the only significant difference among nitrogen contributions of the species in each mix is that weeds produced more N than hairy vetch ($P \leq 0.0073$; **Fig 9**). However, examining the nitrogen contribution of each treatment (cover crop mix + tillage) showed that both conventionally tilled OP and RV contributed more N to the system than strip-tilled RV (with $P \leq 0.0099$ and 0.0016, respectively; **Fig 10**). Moreover, comparing legume percent N between early and late termination dates show unexpected results: when species are held constant, June 15 termination date biomass contained a higher %N than the later termination date on July 15 ($P \leq 0.0036$; **Fig 11**). This suggests, sensibly, that N contribution is more closely associated with biomass production than % N.

Soil Results & Discussion

POX-C was measured on all four soils time points that were collected: immediately before spring tillage, 10d after spring tillage, mid-season, and after harvest was finished. Pre-till POX-C (**Fig 12**) was strongly affected by the interaction of cover crop mix, tillage, and soil location with $P \leq 0.0212$. At the pre-tillage timepoint, both conventionally tilled, between-row OP and RV treatments had greater POX-C than between-row OP-S soil. Between-row OP-S was also lower than its in-row counterpart. However, both differences are difficult to interpret given that no significant soil disruption had yet occurred. No differences were detected at either post-till or mid-season time-points, surprisingly (**Figs 13 and 14**, respectively). After harvest, there was a significant ($P \leq 0.0303$) interaction between cover crop and tillage. Conventionally tilled OP had greater POX-C overall than its strip-till counterpart, and conventionally tilled RV had greater POX-C than the strip-tilled RV treatment (**Fig 15**).

Squash were proliferous. Average treatment yields ranged from 15,759 lb ac^{-1} to 23,276 lb ac^{-1}. However, no difference between treatments was detected (**Fig 16**).

Moving Forward

The experiment will be repeated in 2016, with alterations to the experimental designs to reflect observations and challenges in the first year. 2016 plots will have only three cover crop treatments, within which tillage treatments will be embedded (thus, three total treatments). This includes strip tilled rye+vetch and red clover (fall-seeded on 22 September 2015). These rows are 2.54 m center-to-center to accommodate strip till equipment. The third treatment will be a spring seeded oat+pea mix, which will serve as a conventional tillage control (to be entirely terminated at bed preparation and summer squash seeding). Rows in this treatment will be on a narrower 1.524 m spacing, to reflect a more efficient use of space given that cover crops will not be left to continue growing between rows. All cover crops are seeded with a JP-6 Jang Seeder to ensure accurate seeding rates. Data collection and laboratory analyses are expected to remain the same.

Tables and Figures

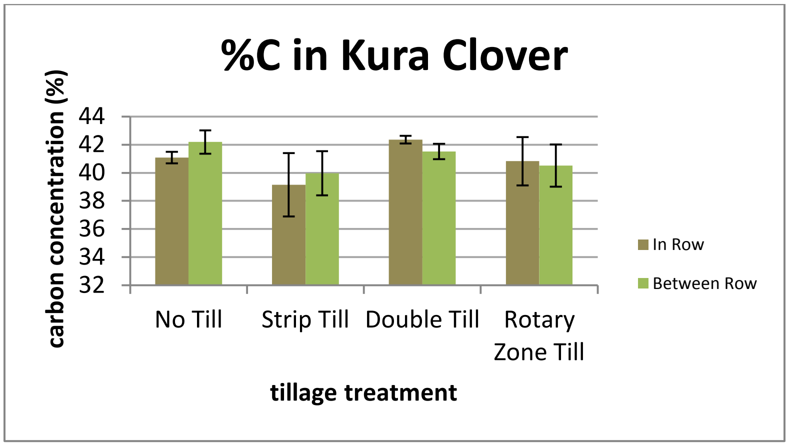
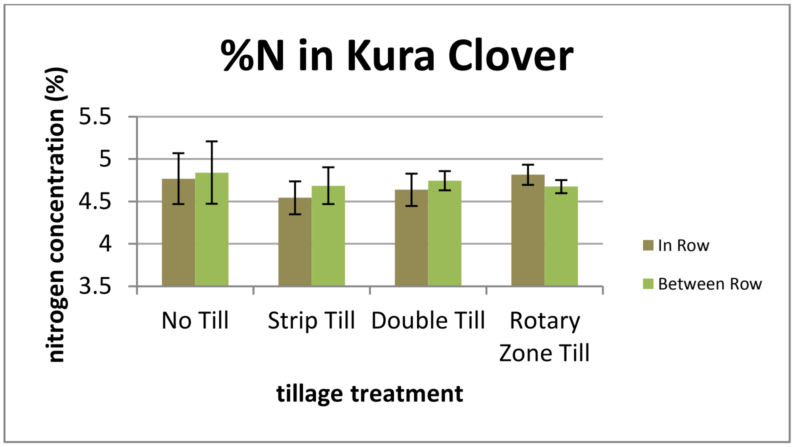


Fig 2



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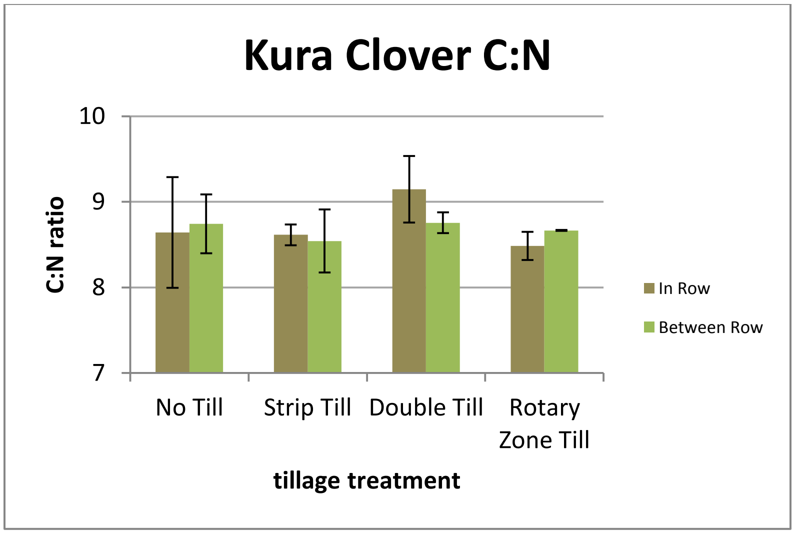

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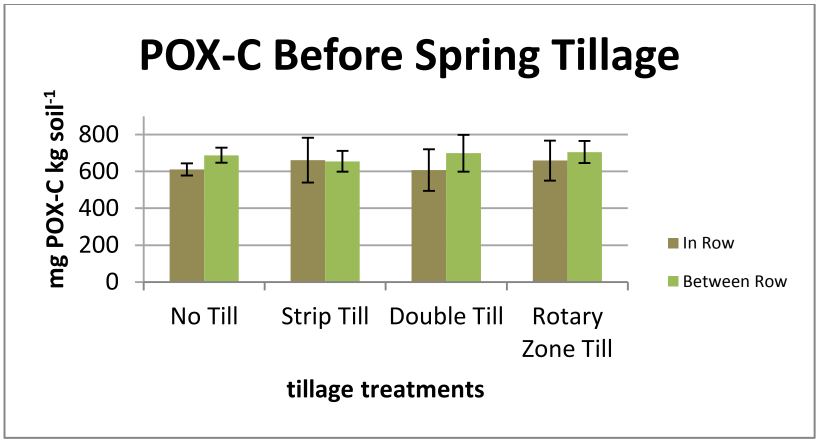
POX-C Before Spring Tillage
mg POX-C kg soil-1
800
600
400
200
0
No Till
Strip Till
Double Till
Rotary Zone Till
tillage treatments
In Row
Between Row

Fig 5

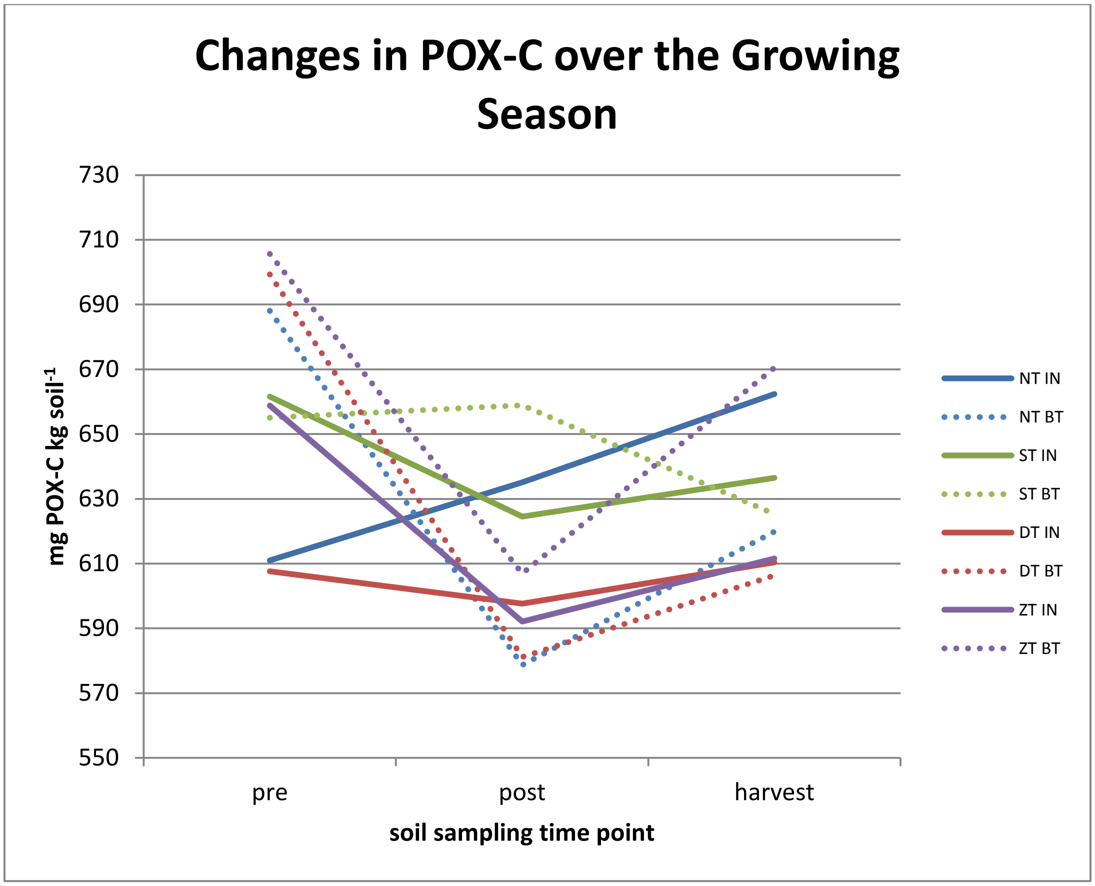
Changes in POX-C over the Growing Season
mg POX-C kg soil-1
730
710
690
670
650
630
610
590
570
550
pre
post
harvest
soil sampling time point
NT IN
NT BT
ST IN
ST BT
DT IN
DT BT
ZT IN
ZT BT

Fig 6

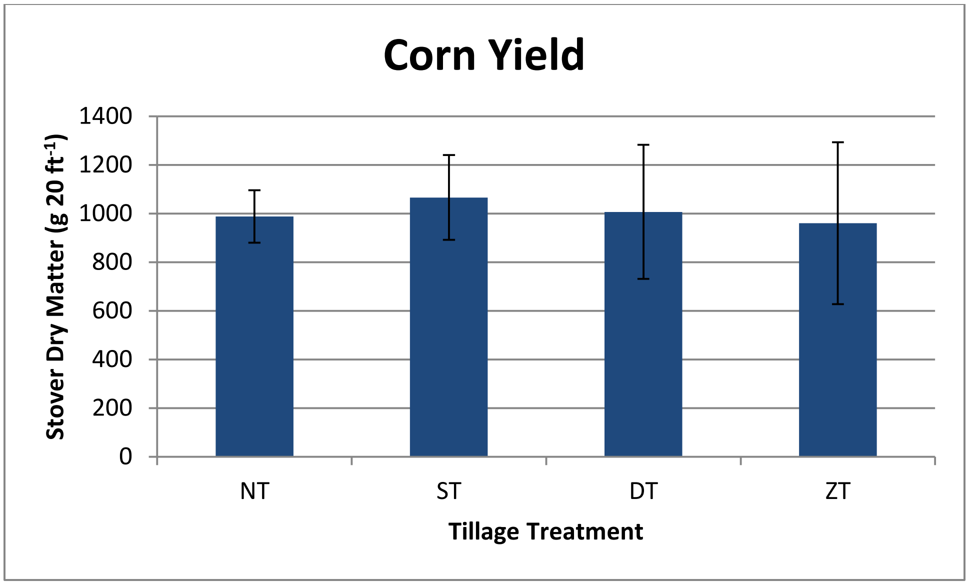
Corn Yield
Stover Dry Matter (g 20 ft^{-1})
1400
1200
1000
800
600
400
200
0
NT
ST
DT
ZT
Tillage Treatment

Fig 7

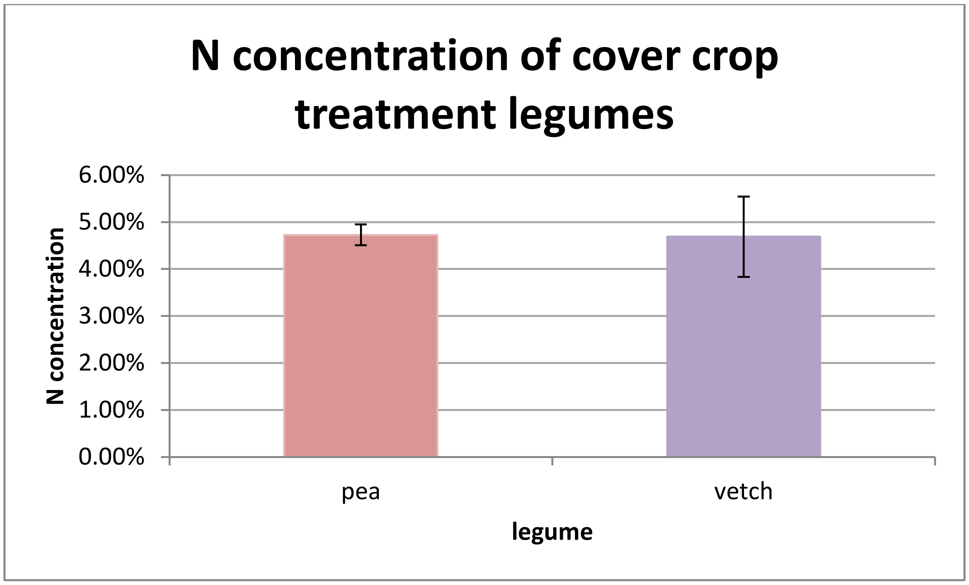
N concentration of cover crop treatment legumes
N concentration
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
pea
vetch
legume

Fig 8

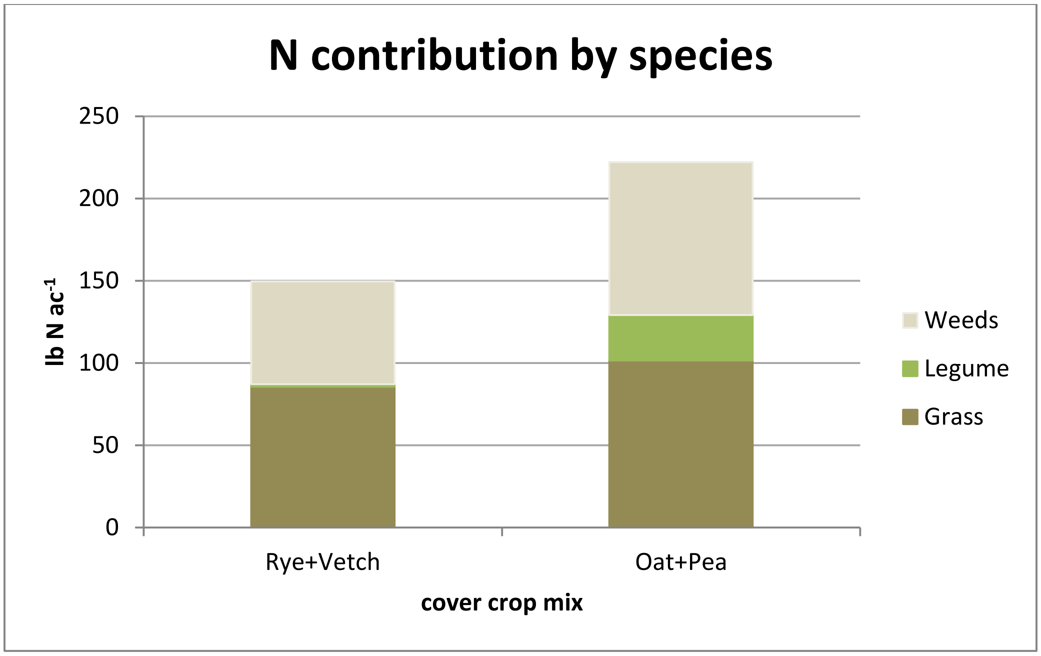
N contribution by species
lb N ac-1
250
200
150
100
50
0
Rye+Vetch
Oat+Pea
cover crop mix
Weeds
Legume
Grass

Fig 9

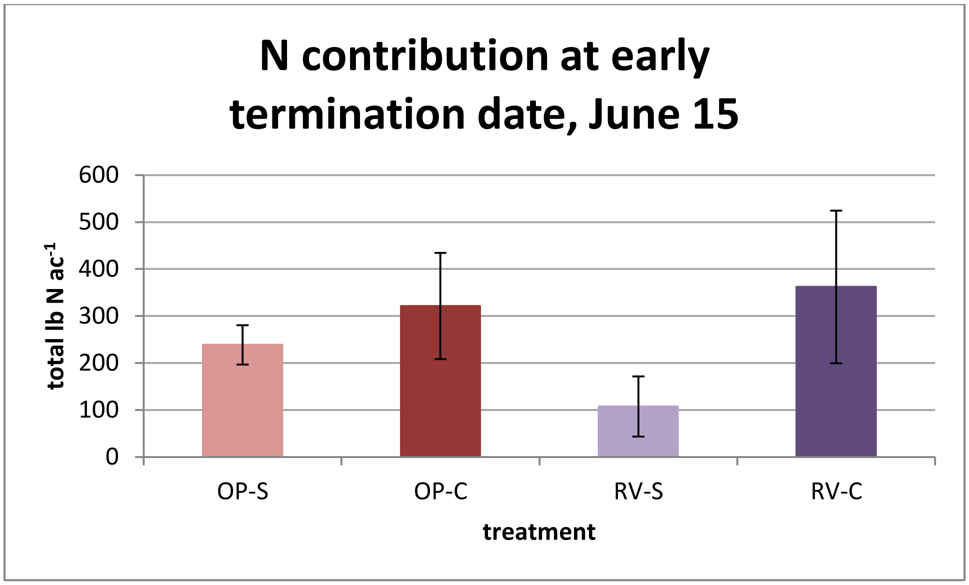
N contribution at early termination date, June 15
total lb N ac-1
600
500
400
300
200
100
0
OP-S
OP-C
RV-S
RV-C
treatment

Fig 10

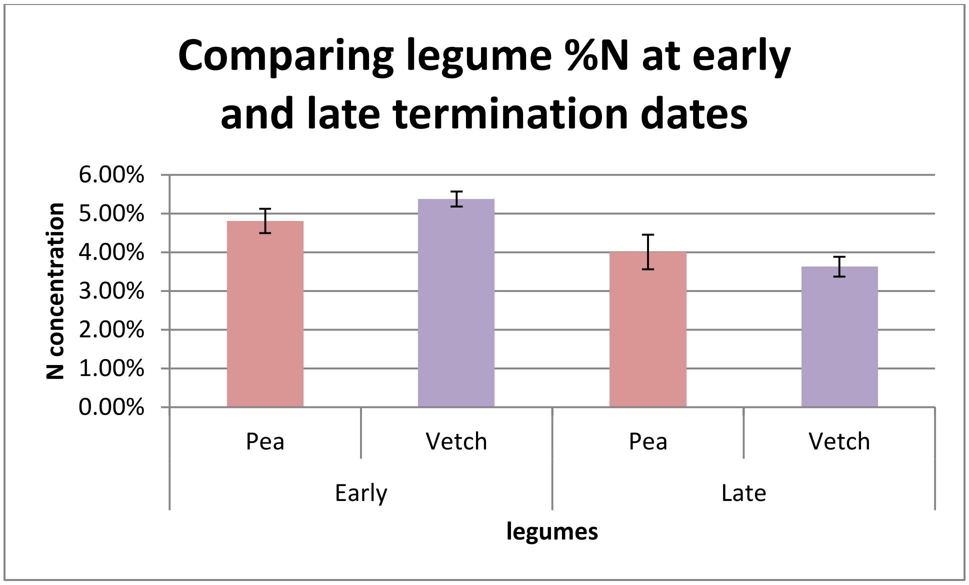
Comparing legume %N at early and late termination dates
N concentration
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Pea
Vetch
Pea
Vetch
Early
Late
legumes

Fig 11

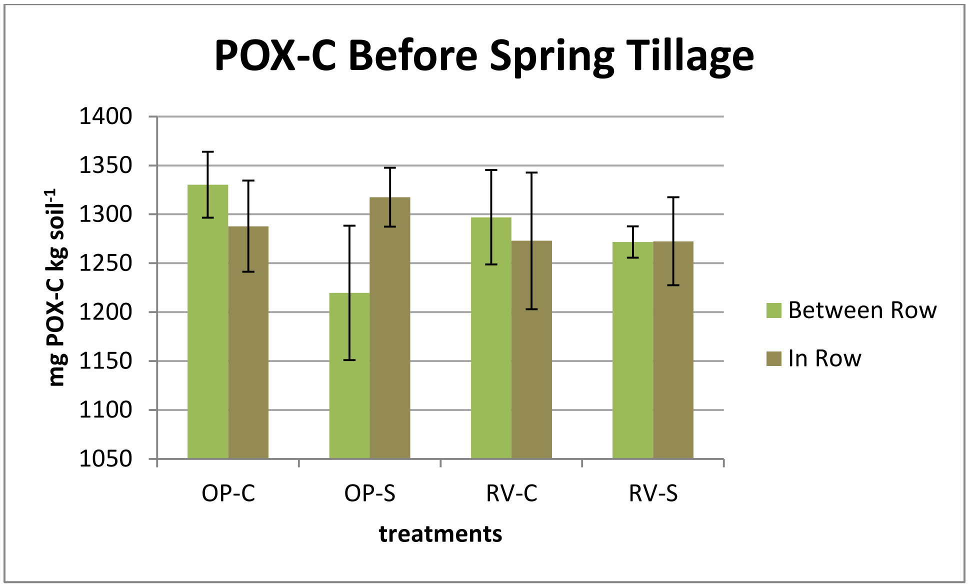
POX-C Before Spring Tillage
mg POX-C kg soil-1
1400
1350
1300
1250
1200
1150
1100
1050
OP-C
OP-S
RV-C
RV-S
treatments
Between Row
In Row

Fig 12

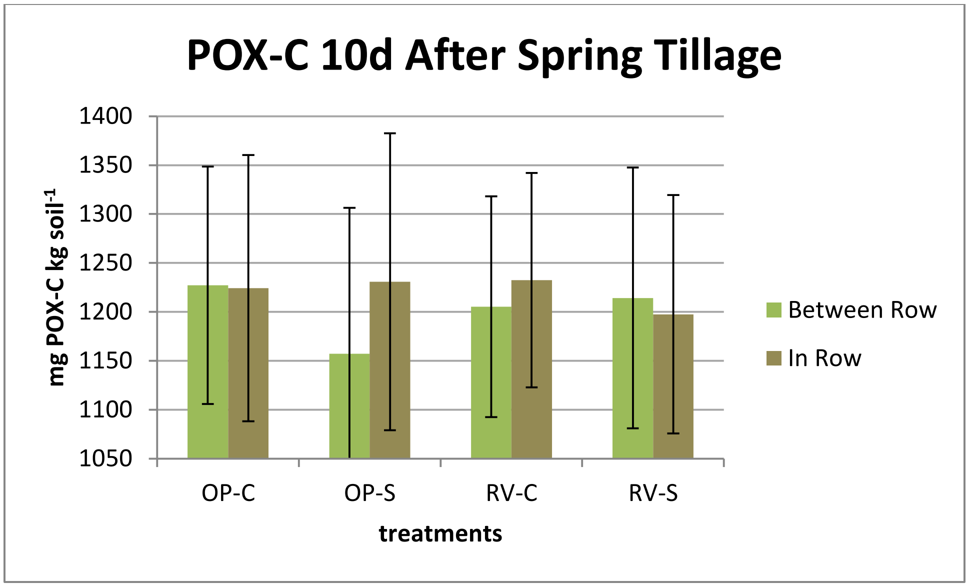
POX-C 10d After Spring Tillage
mg POX-C kg soil^{-1}
1400
1350
1300
1250
1200
1150
1100
1050
OP-C
OP-S
RV-C
RV-S
treatments
Between Row
In Row

Fig 13

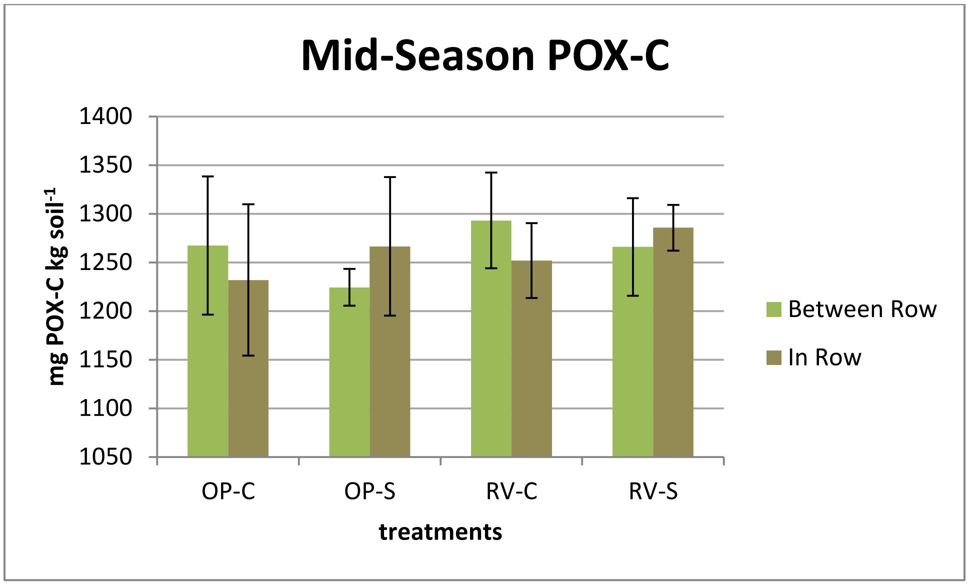
Mid-Season POX-C
mg POX-C kg soil^{-1}
1400
1350
1300
1250
1200
1150
1100
1050
OP-C
OP-S
RV-C
RV-S
treatments
Between Row
In Row

Fig 14

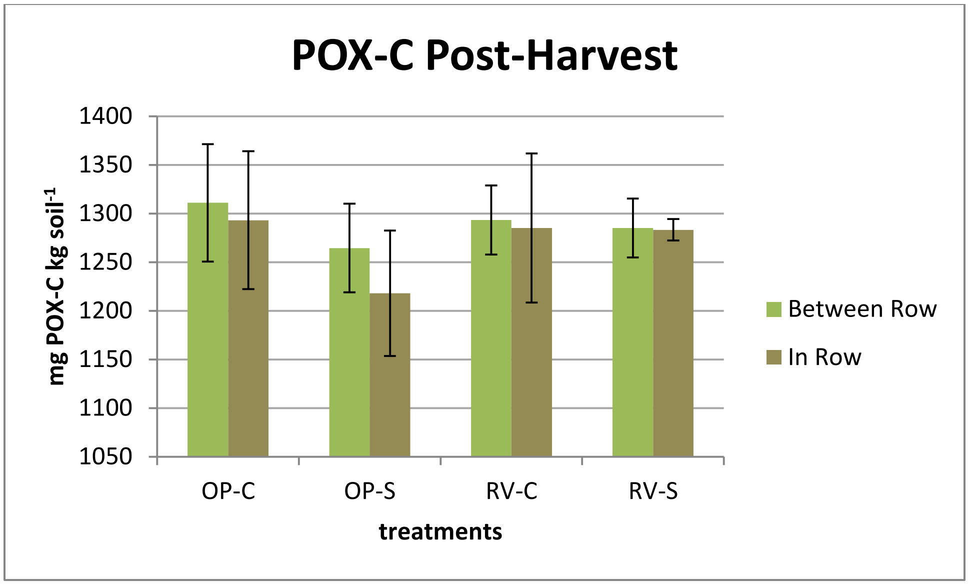
POX-C Post-Harvest
mg POX-C kg soil-1
1400
1350
1300
1250
1200
1150
1100
1050
OP-C
OP-S
RV-C
RV-S
treatments
Between Row
In Row

Fig 15

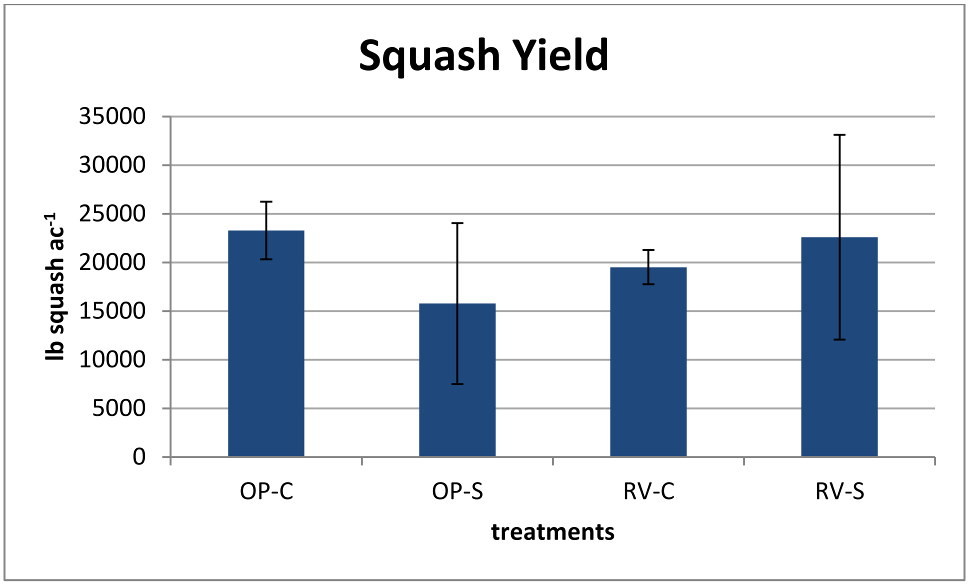
Squash Yield
lb squash ac-1
35000
30000
25000
20000
15000
10000
5000
0
OP-C
OP-S
RV-C
RV-S
treatments

Fig 16

Photos

All photos were taken by Thanwalee “JiJY” Sooksa-Nguan.

Photo 1 –established field of kura clover

Photo 2 – taking biomass cuts from “between-row” area of kura clover

Photo 3 – conventionally tilled plot with bare ground between rows

Photo 4 – laying plastic mulch in a strip till plot, where cover crops remained between rows one month after row creation

Photo 5 – recording weight of one plot's squash yield