Response of Soybean, Sugar Beet and Spring Wheat to the Combination of Reduced Tillage and Fertilization Practices

Kae Miyazawa, Hiroyuki Tsuji*, Makoto Yamagata*, Hiroshi Nakano* and Tomomi Nakamoto

(Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo 113-8657, Japan; *National Agricultural Research Center for Hokkaido Region, Upland Agriculture Research Center, Hokkaido 082-0071, Japan)

Abstract: To evaluate the feasibility of conservation tillage in combination with reduced biocide and fertilization regimes, we conducted a field experiment using conventional and reduced tillage, with or without reduced biocide, and fertilization regimes for growing soybean, sugar beet, and spring wheat in this order for three years. Root biomass and sugar yield of sugar beet did not differ with any combinations of conservation practice. Although leaf biomass was significantly reduced under reduced chemical fertilization (replaced partially with manure compost), it was compensated by a greater specific leaf area. Early crop growth of soybean, and spring wheat was increased to some extent under reduced tillage, which indicated a better nutrient utilization, as well when combined with reduced biocide application. However, reduced fertilization could not supply as much nitrogen as conventional chemical fertilization especially in the combination with reduced tillage. Larger amount or long-term application of organic fertilization may be necessary under reduced tillage compared to the requirement under conventional tillage to compensate for lower rate of nitrogen release from organic matter.

Key words: Manure compost, Nitrogen availability, Reduced tillage, SLA.

There has been an increasing interest in the conservation tillage system since the 1960's, and its adoption has spread in arid, semi-arid and tropical regions in North and South America (Phillips, 1984; Blevins and Frye, 1993; Cannell and Hawes, 1994; Derpsch and Moriya, 1999). The adoption of conservation tillage system in these areas was mainly promoted by a marked yield increase; minimum soil disturbance and cover with plant residue alleviated constraints for crop production in these regions, such as drought, soil erosion and compaction. Development of effective herbicides, which could replace the weeding effect of tillage operations, has supported the practicability of conservation tillage as well.

Better crop performance has been reported under conservation tillage in cool, temperate regions as well. Better vegetation growth of barley and oats was consistently observed under conservation tillage for 14 years in Norway, which may have been caused by a better soil moisture condition under conservation tillage (Børresen, 1993). Slightly higher soybean biomass in early growth was observed under conservation tillage in North Dakota and in Japan which may be associated with stratified nutrients, and enhanced root growth near the soil surface (Ogawa et al., 1988; Deibert and Utter, 1989). Root colonization by AM fungi under less disturbed soil increased phosphorous uptake by crop seedlings in Japan (Usuki et al., 2001), unless non-host crops in the rotation lower the density of AM fungi (McGonigle and Miller, 2000; Karasawa et al., 2002). These benefits should be generally valid in temperate regions, but they are usually small, and often overridden by negative consequences, such as wet hazards and low temperatures in spring, when an inappropriate type of conservation tillage is implemented (Carter, 1994). Conservation tillage in the temperate region therefore has not been very attractive to farmers and its adoption has been limited (Cannell and Hawes, 1994). However, the potential of conservation tillage to promote sustainability of agriculture system irrespective of climatic and soil conditions should be acknowledged (Carter, 1994). Reduction of energy requirements, and enhancement of soil quality and biodiversity in agro-ecosystems are also important benefits of conservation tillage system.

In order to promote conservation tillage as an integral component of sustainable agriculture, evaluation of adoptability in combination with other conservational practices is necessary. Conservation tillage is often coupled with increased rates of herbicide, which may give an adverse impact on agro-ecosystem (McLaughlin and Mineau, 1995). Wetter soil conditions under conservation tillage may accelerate
denitrification, and more developed macropores may result in greater leaching, both of which lead to greater nitrogen loss when large amount of inorganic nitrogen is applied (Blevins and Frye, 1993). If less intensive biocide application and fertilization can be integrated successfully, conservation tillage can be better recognized as a sustainable technique.

Feasibility of conservation tillage combined with the reduced rates of both biocide and chemical fertilizer application, and its potential for improving crop performance are worth exploring. This study presents the performance of soybean, sugar beet and spring wheat cultivated consecutively under the combination of conservation (reduced) or conventional practices of tillage, biocide, and fertilization regimes. Whether the positive effects of reduced tillage persist under the combination of conservational practices, and whether there are any interaction effects on crop production by combining reduced tillage with other conservational practices were investigated.

**Materials and Methods**

1. **Cultural Procedures**

   A field experiment was conducted at the National Agricultural Research Center for Hokkaido Region, Japan (143°3’E, 42°53’N). The soil type at the experimental field is Andosol, loam. The field was prepared in the autumn of 1999 at the site which had been planted with phacelia (*Phacelia tanacetifolia* Benth.) in 1998, and cabbage(*Brassica oleracea* L. var. capitata) in 1999. The experiment was conducted in 2000-2002. Fig. 1 shows climate data during the experiment.

   The design of the experiment was a split-plot with 2 blocks, 16 plots in total (10m×4m area per each plot). Main factors were tillage intensity (CT, conventional tillage; RT, reduced tillage), and biocide quantity (CB, conventional biocide application; RB, reduced biocide application). Sub factor was fertilization (CF, conventional chemical fertilization; RF, reduced chemical fertilization partially replaced with cattle manure compost).

   CT consisted of moldboard plowing to 25 cm in depth after harvest, rotary harrowing and spring-tooth harrowing to 5 cm before seeding. RT was managed only with rotary harrowing to 5 cm before seeding. The moldboard plowing was conducted on Nov. 1 in 1999, Nov. 4 in 2000, and Oct. 25 in 2001. Rotary and spring-tooth harrowing was conducted on May 17 in 2000, Apr. 23 in 2001, and Apr. 16 and 18 in 2002. Crop residues, except for stubbles, were removed from the field.

   CB was based on local standards and conducted with a sprayer. Herbicides used were alachlor and linuron in 2000, lenacil and PAC in 2001, and pendimethalin and linuron in 2002. Insecticides were disulfoton, MEP, and PAP in 2000, acephate, DEP, profenofos, prothiofos, and cyfluthrin in 2001, and fenithrothion in 2002. Fungicides were TPN, mancozeb, mepronil, and thiophanate-methyl in 2001, and fluazinam, propiconazole and chlorothalonil in 2002. In RB, the amount of applied biocides were reduced by about one-third to two-thirds by reducing the application frequency, lowering the concentration, and spraying only on rows whenever possible. After harvest, glyphosate was applied to the plots under RT to substitute a moldboard plowing for weed control, but not with RB. Mechanical weeding was conducted with a cultivator and by hand when necessary.

   CF consisted of application of synthesized fertilizer at a rate of 30, 250, and 130 kg ha⁻¹ of nitrogen, phosphorus pentoxide, and potassium oxide, respectively, in 2000, 144, 240, and 144 kg ha⁻¹, respectively, in 2001, and 80, 200, and 120 kg ha⁻¹, respectively, in 2002. In reduced fertilization treatment (RF), cattle manure compost was applied at a rate of 7 t ha⁻¹ (dry weight) in 2000, 21 t ha⁻¹ in 2001, and 7 t ha⁻¹ in 2002. The nitrogen, phosphorus pentoxide, and potassium oxide contents in manure were, respectively, 1.7%, 0.8%, and 0.6% in 2000, 2.1%, 1.2%, and 0.5% in 2001, and 2.1%, 1.3%, and 0.8% in 2002. To adjust the amount of mineralizable nitrogen, phosphorus, and potassium to those of CF, we applied chemical fertilizer (210 kg ha⁻¹ phosphorus pentoxide and 100 kg ha⁻¹ potassium oxide in 2000, 28 kg ha⁻¹ nitrogen and 44 kg ha⁻¹ potassium oxide in 2001, and 107 kg ha⁻¹ phosphorus pentoxide and 64 kg ha⁻¹ potassium oxide in 2002) to the RF plots. The amount of additional nitrogen was determined on the assumption that the mineralization rate of nitrogen in the manure was 25% of total nitrogen in the applied year, and 10% in the next year. Manure was uniformly broadcasted on the soil surface under RT in 2000-2001 and incorporated into the soil with the rotary harrow both under CT.
RT in 2002.

The plots were planted with soybean (Glycine max (L.) Merr., cv. Toyomusume) on May 23, 2000, at a planting density of 15.4 plant m\(^{-2}\) with 65 cm row spacing. The seeds of sugar beet (Beta vulgaris L. cv. Megumi) were sown on Mar. 12, 2001, in paper pots in a greenhouse, and seedlings were sprayed with imidacloprid and pencycuron. The seedlings were then transplanted on Apr. 27 at a planting density of 7.7 plant m\(^{-2}\) with 65 cm row spacing. Spring wheat (Triticum aestivum L. cv. Haruyutaka) was planted in 2002 at a seeding rate of 16 g seed m\(^{-2}\) with 30 cm row spacing on Apr. 19.

2. Crop Sampling

Soybean was sampled five times; the first on Jun. 14 (unifoliolate leaves developed), the second on Jun. 29 (two trifoliolate leaves developed), the third on Jul. 12 (beginning of flowering), the fourth on Aug. 21 (beginning of pod development) and the fifth on Oct. 5 (at harvest). At each sampling, four plants were randomly chosen per plot, and separated to roots, stems (including petioles), leaves, and pods. Leaf area was measured with images of leaves spread on a wooden plane board. The images were taken by a digital camera (Olympus, CAMEDIA, C-2020Z) and the areas were calculated with Adobe Photoshop 6.0, threshold and histogram functions. The plant samples were oven-dried at 80 °C for two days and weighed, and total nitrogen contents were measured with an NC analyzer (Sumigraph NC-900, SUMIKA; Gas Chromatograph GC-8A, SHIMADZU). At harvest, plants were collected from 2.08 m\(^{2}\) with an NC analyzer (Sumigraph NC-900, SUMIKA; Gas Chromatograph GC-8A, SHIMADZU). At harvest, plants were air-dried for 3 weeks, and above-ground dry weight, grain yield and 1-grain weight (adjusted to 13.5% moisture level) were measured, and ear numbers were counted.

Spring wheat was sampled from 0.45 m\(^{2}\) from randomly chosen 3 rows at every sampling time. Plant, stem and ear numbers were counted, and above-ground dry weight was measured. The first sampling was conducted on May 13, 2002 (two to three leaves developed), the second on Jun. 3 (tillering stage), the third on Jun. 19 (first heading time), the fourth on Jul. 9 (flowering) and the fifth on Aug. 5 (at harvest). Nine plants were randomly chosen from each sample and separated into leaves, stems (including sheaths), and ears. Dry biomass and total nitrogen of each fraction, and leaf area were measured. The root distribution of spring wheat was studied on Jul. 29 by collecting roots from soil samples taken from 3 randomly chosen rows with a boring sampler (diameter of 3.5 cm) at every 5-cm-depths up to 30 cm depth. Roots recovered by wet sieving were dried at 80 °C for two days for weighing. Harvest was from 2 m × 1.2 m quadrat from each plot. Plants were air-dried for 3 weeks, and above-ground dry weight, grain yield and 1-grain weight (adjusted to 13.5% moisture level) were measured, and ear numbers were counted.

3. Soil Sampling

Soil samples for measuring nitrate and ammonium concentrations, total carbon, and total nitrogen were taken 3 times in each year, on Jun. 8, Aug. 23 and Oct. 6 in 2000, Jun. 5, Aug. 22, and Oct. 5 in 2001, and May 9, Jun. 26, and Aug. 20 in 2002. Concentrations of nitrate and ammonium were measured with fresh soil samples collected with a boring sampler (diameter of 3.5 cm) from 0-15 cm depth at 3 randomly chosen spots. Mineralized nitrogen was extracted with 2M KCl and measured with a Flow Injection Analyzer (K-1000, HITACHI) in 2000 and 2002, and with an Auto Analyzer (AACS-II, BRAN LUDBBE) in 2001. Total carbon and nitrogen contents were measured with the same NC analyzer mentioned above. Soil penetration resistance was measured with a cone penetrometer (cross section area, 2 cm\(^{2}\); top angle, 30°) to the depth of 25 cm on May 31 in 2000, May 25 in 2001 and May 1 in 2002. Bulk density was measured on May 7 in 2001 and Apr. 22 in 2002 with the samples collected with a core sampler (2×100 ml for each plot) from 1-6 cm and 8-13 cm depths. Soil moisture was measured with a FDR (DIK-311A, DAIKI) in 2001 and 2002 at 3 randomly chosen spots in each plot at 5 cm depth. The measurement was conducted in ca. one week interval from May to Jul. The intake-rate was measured with twin rings (Clothier, 2001) on May 18 in 2001 and Apr. 23 in 2002 at the site near the experimental plots that received the same tillage treatments. Two PVC pipes (15 cm, and 30 cm diameter) were used. Measurement was replicated 3 times.

3. Data analysis

The significant difference in crop and soil data was
tested by the general linear models (the SAS system, PROC GLM). Main factors and their interaction effects were tested against the residual of the interactions of replicate and main factors (df=3). A sub-factor and the interactions with sub-factor were tested against the residual of the interaction of replicate, main factors and sub-factor (df=4). Correlation matrices were generated by the CORR procedure (PROC CORR) with the plot mean values of each variable. The significance level was set at 5% unless otherwise mentioned.

Effects of biocide and its interaction with other treatments on crop yield, crop quality and soil properties were mostly not significant during three years as shown in tables. The biocide treatment was therefore averaged in figures to be concise.

Fig. 2. Above-ground biomass (a) and nitrogen content (b) during growth period, and yield (c) and yield components (d, pod number; e, seed number per pod; f, 1-seed weight) of soybean in 2000 under the combination of tillage, biocide and fertilization treatments. The abbreviations with capital letters stand for; CT, conventional tillage; RT, reduced tillage; CB, conventional biocide application; RB, reduced biocide application; CF, conventional fertilization; RF, reduced fertilization with manure compost application.

Table 1. Significance of treatment effects on above ground biomass, nitrogen content, yield, yield components and quality parameters of soybean in 2000.

|                      | T | B | F | T x B | T x F | B x F |
|----------------------|---|---|---|-------|-------|-------|
| **Above ground biomass** |   |   |   |       |       |       |
| 22 days (Sampling1)   | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| 37 days (Sampling2)   | n.s. | n.s. | n.s. * | n.s. | n.s. | n.s. |
| 50 days (Sampling3)   | n.s. | n.s. | n.s. * | n.s. | n.s. | n.s. |
| 90 days (Sampling4)   | * | + | * | * | * | * |
| 135 days (Sampling5)  | n.s. | n.s. | n.s. * | n.s. | n.s. | n.s. |
| **Above ground N content** |   |   |   |       |       |       |
| 22 days (Sampling1)   | n.s. | n.s. | n.s. ** | n.s. | n.s. | n.s. |
| 37 days (Sampling2)   | n.s. | n.s. | n.s. *** | n.s. | n.s. + | n.s. |
| 50 days (Sampling3)   | n.s. | n.s. | n.s. ** | n.s. | n.s. | n.s. |
| 90 days (Sampling4)   | n.s. | n.s. | n.s. * | n.s. | n.s. | n.s. |
| 135 days (Sampling5)  | n.s. | n.s. | n.s. * | n.s. | n.s. | n.s. |
| **Yield**             |   |   |   |       |       |       |
| n.s. | n.s. | * | ** | * | n.s. | n.s. |
| **Pod number**        |   |   |   |       |       |       |
| n.s. | n.s. | n.s. | n.s.* | n.s. | n.s. | n.s. |
| **Seed number per pod** | n.s. | n.s. | n.s. ** | n.s. | n.s. + | n.s. |
| **1-seed weight**     | n.s. | n.s. | n.s. * | n.s. | n.s. | n.s. |

T: tillage; B: biocide application; F: fertilization. ***, **, *, + and n.s. represent the significance levels of 0.001, 0.01, 0.05, 0.1, and no significance, respectively.

Fig. 3. Root biomass (a), leaf biomass (b), and their N content (c, d) during growth period, and yield (e), sugar content (f), and impurity contents (g, amino-N; h, potassium; i, sodium) of sugar beet in 2001 under the combination of tillage, biocide and fertilization treatments. Abbreviations follow that of Fig. 2.
Results

1. Crop growth, yield and quality

(1) Soybean

Growth of soybean in 2000 was affected by the tillage, and fertilization treatment. The above ground biomass was significantly smaller under RF from the second sampling to the harvest (Fig. 2a, Table 1), and greater under RT at the second sampling (1.08 g plant\(^{-1}\) in CT, 1.21 g plant\(^{-1}\) in RT). Nitrogen content was lower under RF until the third sampling (Fig. 2b, Table 1). Biomass and nitrogen content of above-ground organs (stem, leaf and pod) responded to tillage and fertilization in a similar way (data were not shown).

Growth analysis was conducted by calculating plant growth parameters in the periods between two samplings. Relative growth rate (RGR) was significantly (<0.01) lower under RF (0.559 g g\(^{-1}\) week\(^{-1}\)) than under CF (0.695 g g\(^{-1}\) week\(^{-1}\)) during 22-36 days (from the first sampling to the second sampling). Net assimilation rate (NAR) responded in a similar manner (p<0.05, 0.45×10\(^{-2}\) g cm\(^{-2}\) week\(^{-1}\) in RF, 0.56×10\(^{-2}\) g cm\(^{-2}\) week\(^{-1}\) in CF).

There was an interaction between tillage and fertilization in soybean yield (Fig. 2c, Table 1). Greater yield under CF compared to RF was more manifested in the combination with RT. Yield can be divided into population density (15.4 plants m\(^{-2}\), constant), pod number per plant, seed number per pod, and 1-seed weight. Among these yield components, seed number per pod showed a similar trend to yield (Fig. 2d-f).

Table 3. Effect of treatments on growth analysis components of soybean in 2001. Relative growth rate (RGR) is a product of net assimilation rate (NAR) and leaf area ratio (LAR: total leaf area of plant divided by total biomass), and LAR is further partitioned to specific leaf area (SLA: leaf area divided by leaf weight) and leaf area ratio (LWR: proportion of leaf weight to total biomass).

| Tillage Biocide | Fertilization | CB | CF | RF | RB | Analysis of variance |
|-----------------|---------------|----|----|----|----|---------------------|
| Root biomass    |               | T  | B  | F  | TxB| TxF| BxF                |
| 65 days (Sampling1) |               | n.s.| n.s.| n.s.| n.s.| n.s.| n.s.                |
| 91 days (Sampling2) |               | n.s.| *  | n.s.| n.s.| n.s.| n.s.                |
| 113 days (Sampling3) |               | n.s.| *  | n.s.| n.s.| n.s.| n.s.                |
| 163 days (Sampling4) |               | *  | n.s.| n.s.| n.s.| n.s.| n.s.                |
| 201 days (Sampling5) |               | n.s.| *  | n.s.| n.s.| n.s.| n.s.                |

Leaf biomass

| 65 days (Sampling1) |               | n.s.| n.s.| n.s.| n.s.| n.s.| n.s.                |
| 91 days (Sampling2) |               | n.s.| *  | n.s.| n.s.| n.s.| n.s.                |
| 113 days (Sampling3) |               | n.s.| *  | n.s.| n.s.| n.s.| n.s.                |
| 163 days (Sampling4) |               | *  | n.s.| n.s.| n.s.| n.s.| n.s.                |
| 201 days (Sampling5) |               | n.s.| *  | n.s.| n.s.| n.s.| n.s.                |

| Yield |               | n.s.| n.s.| n.s.| n.s.| n.s.| n.s.                |
| Sugar |               | n.s.| n.s.| n.s.| n.s.| n.s.| n.s.                |
| K     |               | n.s.| n.s.| n.s.| n.s.| n.s.| n.s.                |
| N     |               | *   | n.s.| n.s.| n.s.| n.s.| n.s.                |
| Amino-N |            | *  | n.s.| n.s.| n.s.| n.s.| n.s.                |

Table 2. Significance of treatment effects on root and leaf biomass, nitrogen content, yield, and impurity contents of sugar beet in 2001.

| Result                  | Treatment                      | Significance |
|-------------------------|--------------------------------|--------------|
| Crop growth, yield and quality |                   |              |
| Soybean                 |                   |              |
| Growth of soybean       |                   |              |
| Nitrogen content        |                   |              |
| Biomass and nitrogen content |               |              |
| Above-ground organs     |                   |              |
| Stem, leaf and pod      |                   |              |
| Tillage and fertilization |                 |              |
| Relative growth rate (RGR) |               |              |
| Net assimilation rate (NAR) |               |              |
| Yield                   |                   |              |
| Population density      |                   |              |
| Pod number per plant    |                   |              |
| Seed number per pod     |                   |              |
| 1-seed weight           |                   |              |
| Interaction             |                   |              |
| Tillage and fertilization |                 |              |
| Growth analysis         |                   |              |
| Plant growth parameters |                   |              |
| Relative growth rate (RGR) |               |              |
| Net assimilation rate (NAR) |               |              |
| Yield                   |                   |              |
| Population density      |                   |              |
| Pod number per plant    |                   |              |
| Seed number per pod     |                   |              |
| 1-seed weight           |                   |              |
| Significance levels     |                   |              |
| 0.01, 0.05, 0.1         |                   |              |
| Abbreviations           |                   |              |
| mature                     |                   |              |
Table 1). Protein and oil concentration of seeds at 10% moisture level did not differ among treatments and were 42.6% and 19.1%, respectively.

(2) Sugar beet
Sugar beet in 2001 responded to the treatments differently in root and leaf (Fig. 3a, b, Table 2). Root biomass was unaffected by fertilization, except for the second sampling when the biomass was greater under RF. On the contrary, leaf biomass was strongly affected by fertilization, and was constantly smaller under RF during the growth period. Nitrogen content was more consistently affected by the fertilization treatment; it was constantly lower under RF and was the lowest under CT at the second sampling both in leaves and in roots (Fig. 3c, d, Table 2).

Growth analysis showed that leaf weight ratio (LWR) and specific leaf area (SLA) were strongly affected by fertilization whereas RGR was not (Table 3). LWR was smaller and SLA was greater under RF during most of the growth period. Since these two components offset each other, the effect of the fertilization on RGR was not significant. Interaction effects of biocide and fertilization were significant in RGR at the period of 45-60 days, but they were not explicable from its components.

Root distribution was greatly affected by the tillage treatment (Table 5). A marked increase of root biomass was found in the uppermost layer (0-5 cm) under RT, and some in the middle layer (10-15 cm) under CT.

Yield of spring wheat was higher under CF compared g/m² on the average. Root yield over treatments was rather low (45.4 t ha⁻¹) compared to the average in Tokachi region (58 t ha⁻¹ in 2001), probably because of Cercospora leaf spot (Cercospora beticola), Aphanomyces root rot (Aphanomyces cochlioides), and Rhizoctonia root rot (Rhizoctonia solani) prevailed in the experimental field in the later season.

(3) Spring wheat
The above-ground biomass of spring wheat was greater under RT at the second and the third sampling (at 10% level of significance; 0.19 and 0.74 under CT, and 0.23 and 0.86 under RT, respectively), and was smaller under RF after the third sampling till the harvest (Fig. 4a, Table 4). Difference between CF and RF was greater under the combination with the RT treatment at the fifth sampling (at 10% level). Nitrogen content of above-ground tissue was constantly lower under RF until the fourth sampling (Fig. 4b, Table 4). Biomass and nitrogen content of above-ground organs (stem, leaf and ear) responded in similar ways to the total plant (data not shown).

Growth analysis detected greater RGR under RT (0.784 g g⁻¹ week⁻¹) than under CT (0.717 g g⁻¹ week⁻¹) at the early season (p<0.01), which may be partly explained by greater SLA (p<0.1, 215 cm² g⁻¹ in RT, 204 cm² g⁻¹ in CT). Significant main effect of biocide and its interaction with tillage were detected in RGR at the period of 45-60 days, but they were not explicable from its components.

Yield distribution was greatly affected by the tillage treatment (Table 5). A marked increase of root biomass was found in the uppermost layer (0-5 cm) under RT, and some in the middle layer (10-15 cm) under CT.

Yield of spring wheat was higher under CF compared
to that under RF (Fig. 4c, Table 4). Although statistically not significant, this trend was enlarged under RT treatment. The yield can be divided into ear number per square meter, grain number per ear, and 1-grain weight. The examination of these yield components showed that no one component explained the above-mentioned differences in the yield (Fig. 4d-f, Table 4). Ear number was lower under RF, but this was compensated by heavier 1-grain weight under RF, especially in combination with CT (at 10% level). Grain number per ear did not show any significant effect. Nitrogen content of grain, which can be an index of protein content, did not differ among treatments. Its average value was 2.3%.

2. Soil properties in relation to the crop yield and quality

The responses of soil chemical and physical properties to the treatment and their correlations with crop yields and qualities, which showed significant responses to the treatments, were tested. Soil nitrate nitrogen concentration was generally lower under RF in the early season (Fig. 5a, Table 6). An exception was found in 2002, where the concentration was higher under RF; the soil samples taken in this year may have reflected the concentration of inorganic nitrogen of inter-rows rather than rows because of narrow banding of chemical fertilizer in this year. The concentration of soil nitrate nitrogen was also affected by the tillage treatment, and was higher under RT in the early-season of 2000 and 2002 (at 10% level), and in the mid-season of 2001. This trend was stronger in the combination with the CF treatment especially in 2000 and 2001. Soil ammonium concentration responded in a similar way as soil nitrate concentration, although not always significantly (Fig. 5b, Table 6). An exception was in 2002, where the concentration was affected by neither tillage nor fertilization. In 2000, these inorganic nitrogen concentrations were positively correlated with amino-N concentration of sugar beet root (early-season NO$_3$-N, $p=0.003$, $r=0.69$; early-season NH$_4$-N, $p=0.042$, $r=0.51$), and with sodium concentration (mid-season NO$_3$-N, $p=0.003$, $r=0.70$; mid-season NH$_4$-N, $p=0.042$, $r=0.51$), and negatively with potassium concentration (early-season NH$_4$-N, $p=0.016$, $r=0.59$; mid-season NO$_3$-N, $p=0.018$, $r=-0.58$; mid-season NH$_4$-N, $p=0.025$, $r=0.56$).

In 2001, these inorganic nitrogen concentrations were positively correlated with amino-N concentration of spring wheat in 2002.

| Tillage | Fertilization | Analysis of variance | T | B | F | T x B | T x F | B x F |
|---------|---------------|---------------------|---|---|---|-------|-------|-------|
| Biocide |               |                      |   |   |   |       |       |       |
|         | CB | CT | RB | CB | CT | RB | CB | CT | RB | CB | CT | RB |
|         |   | 0.778 | 1.214 | 1.886 | 0.934 | 2.719 | 2.558 | 1.644 | 3.522 |
| 0-5cm   |   | 0.961 | 1.015 | 1.128 | 0.725 | 1.623 | 0.426 | 0.530 | 0.430 |
| 5-10cm  |   | 0.754 | 1.301 | 0.834 | 0.560 | 0.352 | 0.244 | 0.375 | 0.303 |
| 10-15cm |   | 0.113 | 0.180 | 0.339 | 0.554 | 0.477 | 0.266 | 0.395 | 0.270 |
| 15-20cm |   | 0.120 | 0.382 | 0.520 | 0.441 | 0.200 | 0.145 | 0.321 | 0.181 |
| 20-25cm |   | 0.206 | 0.294 | 0.294 | 0.300 | 0.197 | 0.255 | 0.466 | 0.203 |
| 25-30cm |   | 0.294 | 0.294 | 0.294 | 0.300 | 0.197 | 0.255 | 0.466 | 0.203 |

***, **, *, +, and n.s. represent the significance levels of 0.001, 0.01, 0.05, 0.1, and no significance, respectively. Abbreviations follow that of Table 3.
carbon content, and soil penetration resistance, however, did not have any correlation with crop properties.

Bulk density in the upper soil layer (1-6 cm) (Fig. 7a, Table 6) was lower under RF in 2001 and 2002 and this was more pronounced under CT in 2001. The bulk density in the lower layer (6-13 cm) was also lower under RF, but not in the combination with RT in 2002. It did not correlate significantly with crop properties.

Table 6. Significance of treatment effects on soil properties.

|        | NO3-N | NH4-N | Total N | Total C | Soil Penetration Resistance 1cm 5cm 10cm 15cm 20cm 25cm 1-6cm 8-13cm early mid late | Bulk Density | Moisture |
|--------|--------|--------|---------|---------|---------------------------------|-------------|---------|
| 2000   |        |        |         |         |                                 |             |         |
| T      | +      | n.s.   | +       | n.s.    | +                               |             |         |
| B      | n.s.   | n.s.   | n.s.    | n.s.    |                                |             |         |
| F      | **     | **     | *       | +       | **                             |             |         |
| T x B  | +      | +      | +       | +       |                                |             |         |
| T x F  | *      | ***    | *       | *       | *                              |             |         |
| B x F  | n.s.   | n.s.   | n.s.    | n.s.    |                                |             |         |

2001
| T      | +      | n.s.   | +       | n.s.    | **                             |             |         |
| B      | n.s.   | n.s.   | n.s.    | n.s.    |                                |             |         |
| F      | **     | +      | +       | +       |                                |             |         |
| T x B  | +      | +      | +       | +       |                                |             |         |
| T x F  | n.s.   | ***    | n.s.    | n.s.    | *                              |             |         |
| B x F  | n.s.   | n.s.   | n.s.    | n.s.    |                                |             |         |

2002
| T      | +      | +      | +       | +       |                                |             |         |
| B      | n.s.   | n.s.   | n.s.    | n.s.    |                                |             |         |
| F      | **     | +      | +       | +       |                                |             |         |
| T x B  | +      | +      | +       | +       |                                |             |         |
| T x F  | +      | +      | +       | +       |                                |             |         |
| B x F  | n.s.   | n.s.   | n.s.    | n.s.    |                                |             |         |

***, **, *, + and n.s. represent the significance levels of 0.001, 0.01, 0.05, 0.1, and no significance, respectively. Abbreviations follow that of Table 1.

Fig. 6. Total soil N and C concentration (a) and penetration resistance (b) under the combination of tillage and fertilization treatments. Abbreviations follow that of Fig. 2.

Fig. 7. Soil bulk density (a) and moisture (b) under the combination of tillage and fertilization treatments, and basic intake rate (c) under tillage treatment. Abbreviations follow that of Fig. 2.
Discussion

Among the three crops investigated, soybean and spring wheat responded to the treatments in a similar way. Greater vegetative growth under RT, which has been found in studies in cool temperate regions (Ogawa et al., 1988; Deibert and Utter, 1989; Børresen, 1993; Usuki et al., 2001) was also observed in early growth stages of these two crops in our experiment. This trend was also valid under the combination with RB. Measurement of soil inorganic nitrogen indicated a better nitrogen supply under RT at the beginning of the growth season, which may have accelerated the crop growth. Slower water infiltration rate under RT, as was shown in basic intake rate, may be one of the possible reasons for the higher inorganic nitrogen concentration under RT. Less leaching loss under RT compared to CT may have maintained more inorganic nitrogen in the upper layer of the soil. Even if denitrification increased under RT, which is anticipated under wet soil condition, the total nitrogen loss was still smaller under RT in our experiment. Whether the nitrogen loss through leaching and denitrification are influenced by conservation tillage depends on soil type and climate (Kitchen et al., 1998), and our results indicated that RT on Brown Andosol in this region can actually improve nitrogen use efficiency by keeping greater amount of inorganic nitrogen available to plants, at least during first three years. Stratification of phosphorus under RT, which is often reported, may also have played some role. Phosphorous availability can be a limiting factor for crop growth in Andosol with high phosphate sorption capacity. Massive root growth of spring wheat under RT in 0-5 cm depth may be a sign of concentrated P in the upper layer (Holanda et al., 1998), which should have facilitated the P uptake by seedling along with other nutrients and water. The effect of AM fungi which potentially facilitates P absorption of crops, on the other hand, was insignificant at least with the soybean in our experiment (data not shown), in which we assumed that the preceding non-host vegetable (cabbage) reduced the density of AM fungi at the level where almost no colonization could occur. Colonization of AM fungi on spring wheat cultivated after sugar beet (non-host) was considered also unlikely.

Better performance of crops under RT, however, disappeared in the middle of the growth period, and was not necessarily resulted in a greater yield when combined with RF. Less mineralization of nitrogen under no-tillage which tends to create a wetter and less aerated soil condition is reported (Thomas and Frye, 1984). Less favorable soil condition for mineralization as well as lack of mechanical incorporation of manure into the soil may have lowered nitrogen release from manure under RT. Theoretically, adequate application of manure compost can improve nitrogen use efficiency by synchronizing nitrogen release with crop growth, and providing nitrogen in later growth periods, e.g. grain/seed filling period (Ma et al., 1999). The crops under CT seemed to benefit better from manure application, as was shown in seed number per pod of soybean (Fig. 3e), which is dependent on photosynthesis after flowering (Egli and Crafts-Brandner, 1996), and 1-grain weight of spring wheat (Fig. 4f). The crops under RT, on the other hand, could not obtain sufficient nitrogen because of less nitrogen release from manure, which may have cancelled the advantages in the early growth. Nevertheless, soil total carbon and nitrogen concentrations were increased under RT and RF by the third year of our experiment, which indicates the accumulation of soil organic matter. This trend may potentially minimize the disadvantages observed in this experiment, by improving soil structure and microbial activities (Eck et al., 1990; Carter, 1992), and even improve the soil conditions for crop production after several years. Increased microarthropod population (Miyazawa et al., 2002) under the combination of RT and RF might also contribute to nutrient availability in long term.

Sugar beet was affected by the treatments in different manner from the other two crops. The RF treatment did reduce N content and leaf growth, but neither root growth, sugar concentration, nor yield. A study conducted in Italy was similar to our result; root yield and sugar content did not differ among different fertilization regimes (mineral fertilization alone, poultry manure alone, and mixed), whilst leaf and crown biomass was greater under the highest rate of mineral fertilization (Giardini et al., 1992). In our experiment, the expansion of thinner leaves (i.e. greater SLA) could explain the gap between leaf and root growth. Developing thinner leaves compensated for smaller leaf biomass under RF. Compared to grain or seed crops, sugar beet may be less sensitive to fertilization regime as long as root yield is concerned. The root quality under less fertilized or organically fertilized soil may be even improved by lowered amino-N content as was shown in our experiment (Fig. 3g). Amino-N is one of the three major impurity contents which impede crystallization and extraction of sugar (Smith et al., 1977). Reduction of nitrogen fertilization has been actually recommended to reduce amino-N content and to increase sugar yield (Draycott and Martindale, 2000).

Along with amino-N, potassium and sodium concentrations are major indices for the sugar beet quality (Smith et al., 1977), in which lower concentration is preferred. Potassium concentration was higher under RF, which may have been caused by the difference in above-ground biomass. Unlike
nitrogen, potassium contained in manure can be utilized by crops much the same as that of chemical fertilizers (Groves et al., 1999). If the same amount of potassium were available and absorbed by sugar beet, its concentration in the plant body would likely be higher under RF because of smaller above-ground biomass. Sodium is easily lost from soil surface by leaching (Eck et al., 1990), thus may have resulted in a higher concentration under RT where leaching was likely to be less. However, the differences in these impurity contents were so small that they did not give a major impact on extractable sugar content in this study. Both potassium and sodium are essential nutrients for sugar beet, and not only potassium but also sodium fertilization is sometimes recommended to realize maximum yields (Durrant and Draycott, 1978; Haneklaus et al., 1998). Unless excessive amount of potassium and sodium exist in the soil, the concentrations of these cations can be controlled by fertilization regimes.

Conclusion
Superior or at least equal yield could be obtained with RT compared with CT in an upland cropping system in Tokachi region. Better nutrient utilization may be realized under RT by less leaching loss of inorganic nitrogen. Vigorous growth of roots near the soil surface may have also promoted the early crop growth. RB did not adversely affect on crop yield even when combined with RT. If organic fertilization is implemented under RT, however, larger amount or long-term application may be necessary compared to the requirement under CT to compensate for the lower rate of nitrogen release from the organic matter.

References
Blevins, R.L. and Frye, W.W. 1993. Conservation tillage: an ecological approach to soil management. Adv. Agron. 51 : 33-78.
Børresen, T. 1993. Ploughing and rotary cultivation for cereal production in a long-term experiment on a clay soil in southeastern Norway. 2. Yields and weed infestation. Soil Tillage Res. 28 : 109-121.
Cannell, R.Q. and Hawes, J.D. 1994. Trends in tillage practices in relation to sustainable crop production with special reference to temperate climates. Soil Tillage Res. 30 : 245-282.
Carter, M.R. 1992. Influence of reduced tillage systems on organic matter, microbial biomass, macro-aggregate distribution and structural stability of the surface soil in a humid climate. Soil Tillage Res. 23 : 361-372.
Carter, M.R. 1994. A reviews of conservation tillage strategies for humid temperate regions. Soil Tillage Res. 31: 289-301.
Clothier, B.E. 2001. Infiltration. In K.A. Smith and C.E. Mullins eds., Soil and Environmental Analysis, Physical Methods. 2 ed. Marcel Dekker Inc., New York. 239-280.
Deibert, E.J. and Utter, R.A. 1989. Growth and NPK uptake by soybean cultivars in northern U.S.A. under reduced tillage systems. Can. J. Plant Sci. 69 : 1101-1111.
Derpsch, R. and Moriya, K. 1999. Implications of soil preparation as compared to no-tillage, on the sustainability of agricultural production: experiences from South America. In M.V. Reddy ed., Management of Tropical Agroecosystems and the Beneficial Soil Biota. Oxford & IBH, New Delhi. 49-65.
Draycott, P. and Martindale, W. 2000. Effective use of nitrogen fertilizer. British Sugar Beet Review 68 : 18-21.
Durrant, M.J. and Draycott, A.P. 1978. Effect of sodium fertilizer on water status and yield of sugar beet. Ann. Appl. Biol. 88 : 321-328.
Eck, H.V., Winter, S.R. and Smith, S.J. 1990. Sugarbeet yield and quality in relation to residual beef feedlot waste. Agron. J. 82 : 250-254.
Egli, D.B. and Crafts-Brandner, S.J. 1996. Soybean. In E. Samski and A.A. Schaffer eds., Photoassimilate Distribution in Plants and Crops. Marcel Dekker, Inc., New York.
Giardini, L., Pimpini, F., Borin, M. and Gianquento, G. 1992. Effects of poultry manure and mineral fertilizers on the yield of crops. J. Agric. Sci. 118 : 207-213.
Groves, S., Chambers, B. and Williams, J. 1999. Potash fertilizer value of farm manures for sugar beet. British Sugar Beet Review 67 : 12-15.
Haneklaus, S., Knudsen, L. and Schnug, E. 1998. Relationship between potassium and sodium in sugar beet. Comm. Soil Sci. Plant Anal. 29 : 1793-1798.
Holanda, F.S.R., Mengel, D.B., Paula, M.B., Carvaho, J.G. and Bertoni, J.C. 1998. Influence of crop rotations and tillage systems on phosphorus and potassium stratification and root distribution in the soil profile. Comm. Soil Sci. Plant Anal. 29 : 2383-2394.
Karasa, T., Kasahara, Y. and Takabe, M. 2002. Differences in growth responses of maize to preceding cropping caused by fluctuation in the population of indigenous arbuscular mycorrhizal fungi. Soil Biol. Biochem. 34 : 851-857.
Kitchen, N.R., Hughes, D.F., Donald, W.W. and Alberts, E.E. 1998. Agrichemical movement in the root-zone of claypan soil: ridge- and mulch-tillage systems compared. Soil Tillage Res. 48 : 179-193.
Ma, B.L., Dwyer, L.M. and Gregorich, E.G. 1999. Soil nitrogen amendments effects on nitrogen uptake and grain yield of maize. Agron. J. 91 : 650-656.
McGonigle, T.P. and Miller, M.H. 2000. The inconsistent effect of soil disturbance on colonization of roots by arbuscular mycorrhizal fungi: a test of the inoculum density hypothesis. Appl. Soil Ecol. 14 : 147-155.
McLaughlin, A. and Mineau, P. 1995. The impact of agricultural practices on biodiversity. Agric. Ecosyst. Environ. 55 : 201-212.
Miyazawa, K., Tsuji, H., Yamagata, M., Nakano, H. and Nakamoto, T. 2002. The effects of cropping systems and fallow managements on microarthropod populations. Plant Prod. Sci. 5 : 257-265.
Ogawa, K., Takeuchi Y. and Katayama M. 1988. Influence of minimum tillage on soil properties and crop yields in Gleyic Andosol. Res. Bull. Hokkaido Natl. Agric. Exp. Stn. 150 : 57-90.*
Phillips, R.E. 1984. Effects of climate on performance of no-tillage. In R.E. Phillips and S.H. Phillips eds., No Tillage Agriculture, Principles and Practices. Van Nostrand Reinhold Company Inc., New York. 152-170.
Smith, G.A., Martin, S.S. and Ash, K.A. 1977. Path coefficient
analysis of sugarbeet purity components. Crop Sci. 17: 249-253.

Thomas, G.W. and Frye, W.W. 1984. Fertilization and liming. In R.E. Phillips and S.H. Phillips eds., No Tillage Agriculture, Principles and Practices. Van Nostrand Reinhold Company Inc., New York. 87-126.

Usuki, K., Tazawa, J., Yamamoto, H. and Katayama, K. 2001. Effect of previous cropping on Arbuscular mycorrhizal formation and growth of maize under no-tillage. Proceedings of the 6th Symposium of the International Society of Root Research. 390-391.

* In Japanese.