Managing Cover Crops for Conservation Purposes in the Fraser River Delta, British Columbia

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1. Introduction

The farmland of the Fraser River delta is some of Canada's most productive because of a unique combination of climate and soil. Much of the cultivated farmland or soil-based agriculture of the Fraser River delta is located within the Municipality of Delta which is part of the highly populated and urbanized environment of the Greater Vancouver Regional District (GVRD). On average, the farmlands of Delta receive about 1000 mm of precipitation per annum, of which approximately 75% falls between November and March (Bomke et al., 1994); and the longest period of frost-free days in Canada, extending from April 15 to October 21. In Delta, the soils are inherently fertile, heavy in texture and deep (Luttmerding 1981); consequently the soil has a good water storage capacity and a potential to sustain crop production on a year-round basis. Approximately 8000 hectares are being farmed in Delta (Klohn et al., 1992). Results from this work should be relevant on similar soils throughout the Georgia Basin of British Columbia and Washington as well as in parts of Western Oregon.

Present day farming in Delta is far below its potential crop productivity (Klohn et al., 1992). The reason for this is related to a number of soil factors, but most notably inadequate sub-surface drainage, deep soil compaction and declining soil organic matter levels. In the past thirty years, about half the farm acreage in Delta has shifted from a mixed farming practice to cultivated vegetable production. At present three quarters of the farmers produce vegetables (i.e. green beans, peas, corn, cabbage and potatoes) with small areas of berries and cereal crops. As a consequence, there have been very significant losses in soil organic matter and associated problems with losses in soil surface structure and with deep soil compaction from working soils that are too wet. Many of the Delta growers view the above as a serious limitation to crop productivity. Some of these degraded fields exhibit uneven seed germination or crop establishment and even crop failures during wet or very dry

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growing seasons. Optimum soil and crop management practices must now be identified which will first reclaim and then sustain these soils at their former or improved capability for crop production. The absence of any significant livestock industry in Delta has greatly limited the availability of soil organic matter inputs such as barnyard manures. Therefore, growing cover crops in Delta as a green manure can help maintain many conservation objectives, such as:

- providing much needed organic matter to the soil;
- protecting and improving the soil surface structure;
- sustaining or increasing earthworm populations;
- reducing the incidence of weeds; and
- providing forage for waterfowl.

The cash crop rotations, soil characteristics, moderate climate and the presence of high numbers of grazing waterfowl combine to give Delta unique constraints for selection of winter cover crops for conservation objectives (Temple et al., 1991). Goals such as winter soil cover and green manuring for soil structure improvement are high priorities while nitrogen conservation is less an environmental imperative than in areas with sensitive groundwater resources.

In this study, a wide range of different cover crop species were screened over a five-year period (beginning in 1991) under conditions of high winter rainfall, poor soil surface structure and intensive waterfowl grazing. Other companion studies to this investigation include the effects of cereal and mixed legume cover crops on soil N cycling (Odhiambo & Bomke, 2000) and the effects of the cover crops on soil environmental parameters such as labile polysaccharides, aggregate mean weight diameter, earthworm numbers and infiltration rates (Hermawan, 1995; Hermawan & Bomke, 1996 ;Liu, 1995). The objective of this study was to screen a wide range of over-winter cover crops with respect to their growth, development, soil surface protection, green manure production and residual soil nitrate (N-uptake) conservation.

2. Materials and methods

2.1 Field sites

In the late summer and fall periods of 1991 through to 1995, cover crop screening trials were established in cooperation with farmers on Westham Island, located within the municipality of Delta, British Columbia. The soils were developed on moderately fine textured deltaic deposits and were mapped as either Westham or Crescent series (Luttmerding, 1981). At each site various cover crops were planted (see Table 1 for planting dates) in the third week of August (early seeding) and third week of September (late seeding). Cover crops were seeded in a randomized complete block design with four replicates. Early and late seeded treatments were conducted on adjacent, but separate experimental areas. The first planting date was to coincide with a cover crop planting after the early harvest of cash crops (i.e. field peas (*Pisum sativum* L.), early harvested potatoes (*Solanum tuberosum* L.) and green beans (*Phaseolus vulgaris* L.), cabbage (*Brassica pekinensis* L.) and corn (*Zea mays* L.). The second planting date was to coincide with the late harvest of cash crops (i.e. green beans, corn, cabbage and potatoes). Soils were lightly disked just prior to planting to incorporate previous crop residues and weeds.

Year	Previous crop	Planting dates: Early seeding	Late seeding	Harvest dates: Fall harvest	Spring harvest
1991/92	Potato	17-Aug	18-Sep	1&15-Nov[1]	8-Apr
1992/93	Green Bean	25-Aug	22-Sep	7-Nov	30-Apr
1993/94	Cabbage	24-Aug	22-Sep	22-Nov	22-Apr
1994/95	Green Bean	23-Aug	20-Sep	21-Nov	27-Apr
1995/96	Potato	23-Aug	23-Sep	12-Nov	7-May

[1]The second late seeding date was harvested two weeks later in fall 1991.

Table 1. Site information for cover crop screening trials

Cover crops were seeded with a Vicon air-seeder at 0.10m row spacings in 3m x 10m plots. Cover crops included fall rye (*Secale cereale* L.; three cultivars), winter wheat (*Triticum aestivum* L.; two cultivars), annual ryegrass (*Lolium multiflorum* Lam.), winter triticale (*Triticum durum x Secale cereale* hybrid; two cultivars), winter barley (*Hordeum vulgare* L.), spring barley (*Hordeum vulgare* L.; three cultivars), spring oats (*Avena sativa* L.), spring wheat (*Triticum aestivum* L.), forage rape (*Brassica napus* L.), forage kale (*Brassica oleracea var. acephala* L.), crimson clover (*Trifolium incarnatum* L.), alsike clover (*Trifolium hybridum* L.) and red clover (*Trifolium pratense* L.). Sudan grass (*Sorghum sudanense* L.), Austrian winter peas (*Pisum sativum* L.) and buckwheat (*Fagopyrum esculentum* L.) were also included in the first year. Refer to Table 3 for cultivars used and planting densities.

2.2 Plant sampling methods

The cover crops were hand clipped (see Table 1 for harvest dates) using 0.25 m^2 quadrats in November when some of the crops began to show signs of die-back (frost damage) and when fields were beginning to become too soft to walk on because of heavy November rains. Plots were sampled again in April just prior to the preparation of seedbeds for planting summer crops. Sub samples were oven-dried for 72 h at 65^{o}C and all biomass yields are given on a dry weight basis. A sub sample was ground (1mm sieve), digested according to the Parkinson and Allen (1975) method and analyzed for total N using a Technicon Auto analyzer (Technicon, 1974). In November, cover crops were measured or visually rated for cover (point method), early establishment, cold tolerance and height. Weed control assessments were made in April, just prior to plow down, and based upon % cover.

2.3 Statistical analysis

Seeding of early and late cover crop planting dates was analyzed separately. The analyses were conducted using Analysis of Variance (ANOVA) and General Linear Models (GLM) procedure of windows SAS Version 9.1 (SAS Institute, Cary, NC). For plant biomass and N-uptake, mean values were compared using Duncan's multiple range test following a significant F value at P=0.05.

3. Results and discussion

3.1 Climate and weather conditions

Table 2 presents the 30-year normal and monthly temperatures and precipitation for the years that the screening trials were performed. Relative to the normal precipitation for the

November to April cover crop growing season, November 1991-92 was about average, January and April were wetter months, while December, February and March were drier. November and March of 1992-93 were about average; April was wetter, while December, January and February were drier months than normal. The 1993-94 field season's (El Niño year) November and January were relatively dry, while December, February, March and April were about average. November and January of 1994-95 were wetter months, while December, February, March and April were about average. The 1995-96 field season's November, December and April were wetter; January and February were about average and March was a drier month. With the exception of the warm December of 1991 and colder than normal January of 1993, monthly temperatures did not appear to vary enough from the 30-year normal temperatures to greatly influence crop performance.

Mean Monthly Temperature (oC)							
Month	30yr. Normal	1991	1992	1993	1994	1995	1996
Jan	3.0	1.6	5.8	-0.4	6.3	4.5	2.9
Feb	4.7	7.1	6.6	3.5	3.7	5.3	4.3
Mar	6.3	5.4	8.5	7.4	7.2	7.1	6.8
Apr	8.8	8.8	10.6	10.0	10.9	9.6	10.4
May	12.1	12.3	13.5	14.7	13.8	14.2	11.7
Jun	15.2	14.6	17.2	15.8	15.0	16.7	15.2
Jul	17.2	17.8	18.4	16.4	18.5	18.5	18.2
Aug	17.4	18.0	17.8	17.6	18.5	16.5	18.1
Sep	14.3	14.9	13.9	14.8	15.7	16.6	13.7
Oct	10.0	9.2	11.3	11.4	10.2	10.4	9.6
Nov	6.0	7.1	6.4	4.5	5.0	8.0	5.0
Dec	3.5	5.6	1.9	4.5	4.4	4.7	1.4
Total Monthly Precipitation (mm)							
Month	30yr. Normal	1991	1992	1993	1994	1995	1996
Jan	149.8	156.8	281.8	103.4	112.5	164.4	160.4
Feb	123.6	143.3	87.8	11.4	108.2	140.1	110.8
Mar	108.8	106.4	25.9	115.2	103.2	110.9	70.3
Apr	75.4	111.3	126.2	126.9	65.0	54.4	171.5
May	61.7	60.2	15.8	100.8	39.6	27.2	72.3
Jun	45.7	53.6	96.4	72.2	70.5	46.0	13.6
Jul	36.1	33.6	27.1	34.3	27.4	43.4	17.2
Aug	38.1	170.0	23.2	19.0	18.0	69.5	33.8
Sep	64.4	8.8	48.2	2.1	65.6	15.2	69.8
Oct	115.3	27.1	109.1	73.1	113.0	141.4	249.6
Nov	169.9	192.4	168.3	63.1	205.2	251.7	214.5
Dec	178.5	95.8	117.8	162.3	189.1	221.0	280.6
TOTALS	1167	1159	1128	884	1117	1285	1464

Table 2. 30 year normal and monthly temperature and precipitation for study area as recorded at Vancouver International Airport (source: Environment Canada).

3.2 Growth, development and soil surface protection

Sudan grass barely emerged and died very quickly after the first frost. Buckwheat established well, but produced very little biomass and it too died very quickly after the first frost. Winter peas did not establish well and were subject to high disease pressure. The sudan grass, buckwheat and winter peas were subsequently covered by weeds. None of these three cover crops warranted sampling and are not recommended for over-winter cover cropping in this region. Hence they are not considered under results and discussions. Table 3 presents the cover crop biomass yields and Table 4 summarizes some of the field observations with respect to establishment, % cover and cold tolerance, November sampling height of crops, and weed control for each of the most commonly used cover crops in the screening trials. With the exception of triticale, red clover and alsike clover, all of the cover crops seeded in the third week of August achieved 80 -100% cover. Spring cereals (wheat, barley and oats) fall rye, winter barley, winter wheat, annual ryegrass and forage rape all gave adequate winter cover. Given reasonable conditions for emergence and moderate drainage, the crimson clover seeded in August produced satisfactory cover. Complete soil cover often occurred in the absence of an extensive cover crop canopy as weeds, especially chickweed (*Stellaria media* L.) filled in bare areas. Over-winter weed control was usually directly related to the cover crops' ability to rapidly establish soil cover. It should also be noted that early seeded cereals, in particular spring and winter barley, triticale and spring oats, were frequently infected with fungal diseases including brown leaf rust, septoria and powdery mildew. These could increase the need for fungicide sprays when over-wintering cereals are used as cover crops in crop rotations with a high proportion of cereals as cash crops.

The use of similar crop species as winter and summer cash crops can provide an undesirable "green bridge" enabling the survival of pests common to both. This concern could also apply to the use of *Brassica* cover crops, forage rape and kale, when the crop rotation includes cabbage, cauliflower etc. Poor establishment of Austrian winter peas in the single trial in which it was planted may indicate a similar negative relationship to crop rotations that include processing peas.

The accumulation of cover crop biomass is directly related to its ability to improve soil structure and to take up and conserve residual nitrogen prior to the winter rainy period. In this regard, the cover crops screened in our trials fall into three categories: 1) frost sensitive spring cereals; 2) true winter cereals; and 3) species which grow rapidly in the fall, yet exhibit good cold tolerance. With the exception of frost sensitive cover crops, such as spring barley and oats, much of the biomass accumulation occurs in the spring regardless of the planting date. Examples of the latter group are 'Aubade' annual ryegrass, 'Danko' fall rye and the spring wheat cultivar 'Max'. These crops have proven to be effective in relatively cold growing conditions; continuing growth even after frosts and during cool temperatures during the winter. Therefore these cover crops are recommended for late planting dates.

The frost-sensitive spring cereals were barley cultivars 'Virden', 'Harrington' and oat cultivars 'Winchester' and 'Cascade'. Winter-kill of spring cereals, which resulted in good straw mulch, only occurred with crops planted early. Late planted spring cereals did not die-back, became diseased and provided little soil surface protection. There were a few differences among the spring cereals; for example, early-planted spring oats produced less biomass than the spring barley cultivars by the end of fall 1992. The differentiation among spring barley cultivars is small enough that farmers requiring a cover crop that will winter-kill can choose from any of the above cultivars depending on price and availability. Spring barley is preferred over oats because we observed good control of spring weeds, likely due to allelopathic effects. 'Virden' barley, because of its higher grain yields when grown locally and its straw strength should have lower costs of seed production and may be a good cultivar to emphasize.

		Fall & Spring dry matter yields (t/ha) for early & late pl					
Year:		1991/92				19	
Harvest dates[1]:		Fall		Spring		Fall	
Planting dates[1]:		Early	Late	Early	Late	Early	Late
Cover Crop; *Variety*	Planting rate (kg/ha)						
Fall rye; *Ladner Common*	100	2.93 efg**	0.65 c	6.40 cd	5.91 bc	1.37 bcd	1.20 a
Fall rye; *Danko*	100	3.61 def	0.94 abc	5.19 cd	3.98 cd	1.68 ab	0.78 b
Fall rye; *Kodiac*	100	------*	------	------	------	------	
Winter wheat; *Monopol*	100	2.71 fg	0.68 bc	7.44 bc	6.79 b	1.07 cd	0.32 de
Winter wheat; *Fundelea*	100	------	0.58 c	------	7.89 ab	------	------
Annual ryegrass; *Aubade*	25	4.01 cde	0.57 c	8.89 ab	6.84 b	1.43 bc	0.32 de
Winter triticale; *Wintri*	100	3.39 efg	0.67 bc	7.24 bc	3.51 d	0.94 d	NH
Winter triticale; *Pika*	100	------	------	------	------	------	------
Winter barley; *Elmira*	100	3.13 efg	0.97 abc	6.42 cd	4.49 cd	1.38 bcd	0.25 e
Spring barley; *Winchester*	100	5.58 ab	0.83 abc	WK	3.51 d	1.75 ab	0.50 cd
Spring barley; *Harrington*	100	5.78 a	1.08 abc	WK	WK	1.69 ab	0.56 bcd
Spring barley; *Virden*	100	5.58 ab	1.28 ab	WK	WK	2.08 a	0.57 bc
Spring oats; *Cascadia*	100	5.36 ab	1.11 abc	WK	5.93 bc	1.16 cd	NH
Spring wheat; *Max*	100	5.01 abc	1.14 abc	WK	9.11 a	1.09 cd	0.25 e
Forage rape; *Liratop*	10	4.52 bcd	1.43 a	9.97 a	6.73 b	1.77 ab	0.49 cde
Forage kale; *Premier*	8	------	------	------	------	------	0.45 cde
Crimson clover; *Common*	18/12**	2.41 g	------	4.31 de	------	NH	------
Alsike clover; *Common*	7	0.73 h	------	2.10 f	------	------	------
Red clover; *Pacific Red*	12	1.28 h	------	2.74 ef	------	NH	------
p-values:		0.0001	0.0256	0.0001	0.0001	0.0001	0.0001
C.V.:		19.4	30.1	23.4	21.9	20.4	28.9

[1]See Table 1 for planting and harvest dates.
*Cover crop not planted in that year or on that date.
**Means in the same column followed by the same letter are not significantly different; alpha=0.05.
#WK = winter kill; NH = insufficient sample to harvest, height less than 5 cm.
**Seeding rate; 18kg/ha in 1991/92 & 1992/93; 12 kg/ha in 1993/94 & 1994/95.

Table 3. Cover crop screening trials: Yearly harvest above ground dry matter yields

Fall & Spring dry matter yields (t/ha) for early & late planting dates

1993/94				1994/95				1995/96			
Fall		Spring		Fall		Spring		Fall		Spring	
Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
------	------	------	------	------	------	------	------	------	------	------	------
1.30 def	0.59 c	2.73 c	2.81 d	2.38 bc	1.57	5.67 b	4.26 a	------	------	------	------
------	------	------	------	------	------	------	------	4.17 a	NH	6.46	5.51 b
1.55 cdef	0.43 d	5.79 a	4.85 b	1.80 cd	NH	9.90 a	5.63 a	2.87 b	NH	9.43	4.76 bc
------	------	------	------	------	------	------	------	------	------	------	------
2.08 bcd	0.28 e	5.11 ab	4.24 bc	0.97 d	NH	8.12 a	5.18 a	4.70 a	NH	7.40	10.8 a
------	------	------	------	------	------	------	------	------	------	------	------
1.22 ef	0.45 cd	3.26 bc	3.31 cd	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------	------	------	------
2.74 ab	0.75 b	WK	WK	3.68 a	1.65	WK	WK	2.91 b	NH	WK	3.92 c
1.99 bcde	0.43 d	WK	WK	------	------	------	------	------	------	------	------
3.27 a	0.50 cd	WK	6.71 a	3.12 ab	1.04	WK	5.54 a	4.55 a	NH	WK	5.45 b
2.26 bc	1.04 a	2.17 c	4.98 b	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------	------	------	------
1.09 f	NH	3.53 bc	1.06 e	0.97 d	NH	4.93 b	1.90 b	------	------	------	------
------	------	------	------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------	------	------	------
0.0001	0.0001	0.0151	0.0001	0.0001	0.2196	0.0011	0.0005	0.0005	------	0.1450	0.0001
26.5	17.1	36.8	19.8	28.6	33.3	17.4	22.6	13.9	------	23.8	13.1

Table 3. Continued

		Early Plantings[1]				Late Plantings[1]		
Cover crop	Early Establishment	Nov. % cover	Cold Tolerance	Nov. height (cm)	Weed Control	Nov. % cover	Cold Tolerance	Nov. height (cm)
Fall rye cv. *Danko*	VF	85-100	H	15-30	G	50-80	H	5-15
Winter wheat cv. *Monopol*	M-F	85-100	H	20-25	G	50-70	H	5-15
Annual ryegrass cv. *Aubade*	VF*	90-100	H**	25-35	G***	60-80	H	5-15
Spring wheat cv. *Max*	F	90-100	M	35-55	G	45-75	H	5-15
Spring barley cv. *Virden*	VF	90-100	L	50-70	G	65-85	M	15-30
Winter barley cv. *Elmira*	F	80-100	M	10-15	G	65-80	H	5-10
Winter triticale cv. *Wintri*	S-M	60-80	H	<5	F	20-40	H	<5
Oats cv. *Cascadia*	VF	90-100	L	45-60	F	45-70	H-M	15-20
Forage rape cv. *Liratop*	VF	90-100	H	25-30	G	60-90	H	5-10
Alsike clover cv. *Common*	S	40-50	H	5-10	F	N/A#	N/A	N/A
Red clover cv. *Pacific Red*	S-M	60-80	H	5-10	F	N/A	N/A	N/A
Crimson clover cv. *Common*	M	90-100	H	10-15	F	20-30	H	<5

[1]See Table 1 for planting dates
*Early establishment: F=fast, M=medium, S=slow, VF=very fast, VS=very slow
**Cold tolerance: H=high, M=moderate, L=low; cover crops with a low cold tolerance usually winter kill; cover
tolerance may winter kill; and cover crops with a high cold tolerance do not winter kill and grow will under wet
***Weed control: P=poor, F=fair, G=good; the most dominant weed was chickweed.
#N/A = not applicable; too slow to establish, therefore not recommended for planting late in growing season.

Table 4. Cover crop screening trials: General field observations for commonly used cover crops.

The true winter cereals (i.e. requiring a cold period for vernalization) were fall rye (Ladner common and the cultivars 'Danko' and 'Kodiac'), winter wheat ('Monopol' and 'Fundelea'), winter barley ('Elmira') and triticale ('Wintri' and 'Pika'). In general, the fall ryes lived up to their reputation for hardiness, disease resistance and growth under cold or cool conditions. By spring plow-down, fall rye ranked among the best cover crops in both dry matter yields and cover. Satisfactory performances were also obtained from early-planted 'Monopol' winter wheat and 'Elmira' winter barley. However, 'Wintri' triticale did not yield well as a green manure crop and did not produce much cover (60-80%) or dry matter and 'Elmira' winter barley and 'Fundelea' winter wheat were heavily infested with fungal diseases.

A successful winter cover crop in this area should establish satisfactory soil cover prior to December and the onset of cold temperatures and high rainfall conditions. Cover, either dead or alive, should be maintained until field operations begin the next spring. It is clear that, aside from the particular crop planted, the date of seeding and soil conditions at seeding are the most important determinants of good cover or biomass yields and residual soil nitrate conservation. Cover crops that established rapidly and provided soil cover, good weed control, low incidence of disease, and relatively good biomass yields over the first two years of this screening trial were: 'Danko' and 'Kodiac' fall rye; 'Monopol' winter wheat; 'Aubade' annual ryegrass; 'Virden' spring barley; and 'Max' spring wheat. Therefore, for the final three years of the screening trials, these cover crops continued to be planted and monitored; and are now the subject of further discussion with respect to their five year comparative performance in green manure production and residual soil nitrate conservation.

3.3 Green manure production

Cover crop biomass production prior to winter for the five selected crops is presented in Table 5 for early and late planted cover crops. Delaying planting until the third week of September dramatically reduced fall dry matter production from a range of 2-5 to < 1.5 t ha^{-1}. When planted in August, spring barley and spring wheat were the highest yielders, joined by fall rye and annual ryegrass in two of the five years. In most years, early seeded spring wheat and spring barley winter-killed with little additional biomass production after the onset of winter.

For the winter hardy crops, the spring harvest, usually in April, indicates the crops' potential for green manure production (Table 5). For the cover crops seeded during the third week of August, winter wheat consistently produced high amounts of green manure, to a maximum of 10 t ha^{-1} in spring 1995. Annual ryegrass yielded 5 to 9 t ha^{-1} of dry matter prior to spring plow-down. Fall rye usually yielded less biomass than annual ryegrass or winter wheat. Interestingly, spring wheat seeded later consistently survived the winter as did spring barley in two of five years. In fact, spring wheat was the top green manure crop in three of five years and did consistently well in all years.

Annual ryegrass yielded the most green manure of any September seeded cover crop in 1996 and performed consistently well in other years. Winter wheat and fall rye ranked differently from year to year, but were generally lower yielding than spring wheat or annual ryegrass.

Early-planted cover crops produced half of their total biomass prior to winter as compared to late-planted crops, which produced only 5 to 36% of their total biomass prior to winter. Cover crop biomass production prior to winter declined dramatically with later planting dates. Much of the biomass production by the late-planted cereals occurred during late

	Early planted[1]: approximately the third week of August.										Late planted[1]: approximately the thi				
	1991/92		1992/93		1993/94		1994/95		1995/96		1991/92		1992/93		19
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	M
Fall harvest[1]:															
Dry weights (t/ha)	p=0.0093		p=0.0010		p=0.0010		p=0.0006		p=0.0005		p=0.0331		p=0.0008		p
Fall rye	3.61	1.15 bc*	1.68	0.45 ab	1.30	0.46 c	2.38	0.52 bc	4.17	1.07 a	0.94	0.37 abc	0.78	0.28 a	0.
Winter wheat	2.71	0.69 c	1.07	0.57 c	1.55	1.00 c	1.80	0.13 cd	2.87	0.11 b	0.68	0.25 bc	0.32	0.16 b	0.
Annual ryegrass	4.01	0.90 bc	1.43	0.31 bc	2.08	0.19 bc	0.97	0.55 d	4.70	1.08 a	0.57	0.19 c	0.32	0.17 b	0.
Spring wheat	5.01	0.72 ab	1.09	0.39 c	3.27	1.09 a	3.11	1.08 ab	4.55	0.44 a	1.14	0.30 ab	0.25	0.11 b	0.
Spring barley	5.58	1.22 a	2.08	0.88 a	2.74	0.44 ab	3.68	0.41 a	2.91	0.40 b	1.28	0.28 a	0.57	0.11 a	0.
N concentration (%N)	p=0.0011		p=0.0006		p=0.0001		p=0.0002		p=0.3460		p=0.6183		p=0.0044		p
Fall rye	2.60	0.44 a	2.97	0.55 cd	2.25	0.21 b	2.62	0.25 bc	2.61	0.32	4.61	0.66	3.88	0.49 b	4.
Winter wheat	2.73	0.23 a	3.50	0.35 ab	2.76	0.20 a	3.24	0.06 a	2.70	0.57	4.56	0.34	3.16	0.78 c	4.
Annual ryegrass	2.74	0.13 a	3.22	0.24 bc	2.20	0.12 b	2.77	0.20 b	2.97	0.36	4.69	0.15	4.30	0.27 ab	5.
Spring wheat	2.25	0.50 a	3.78	0.51 a	2.13	0.30 b	2.82	0.24 b	2.67	0.39	4.69	0.21	4.56	0.16 a	5.
Spring barley	1.49	0.28 b	2.65	0.23 d	1.54	0.25 c	2.41	0.11 c	3.12	0.27	4.31	0.30	4.02	0.12 ab	4.
N content (kg/ha)	p=0.0977		p=0.0041		p=0.0098		p=0.0003		p=0.0078		p=0.0180		p=0.0002		p
Fall rye	92.9	28.0	48.9	12.8 ab	29.0	10.0 b	61.3	6.6 b	110	35.7 ab	41.8	13.8 ab	29.3	6.2 a	27
Winter wheat	75.0	23.1	36.8	17.0 c	42.9	27.0 b	58.4	5.5 b	77.4	16.2 c	30.7	10.7 b	10.0	2.6 b	18
Annual ryegrass	109	21.1	45.7	8.5 ab	45.7	4.6 b	26.5	14.2 c	138	26.8 a	26.8	9.2 b	13.7	2.7 b	15
Spring wheat	113	28.2	40.9	14.0 bc	68.8	21.5 a	86.1	24.8 a	123	29.3 ab	53.1	11.7 a	11.5	5.2 b	26
Spring barley	82.1	18.9	53.7	18.5 a	41.6	5.2 b	88.6	9.1 a	91.4	18.8 bc	54.9	10.4 a	22.9	3.6 a	30

[1]See Table 1 for planting and harvest dates.
[#]WK = winter kill; NH = insufficient sample to harvest, height less than 5 cm.
**Means in the same column followed by the same letter are not significantly different; alpha=0.05.

Table 5. Selected early and late planted cover crops for fall and spring harvest annual above ground
concentration and content comparisons

	Early planted[1]: approximately the third week of August.										Late planted[1]: approximately the third week of September									
	1991/92		1992/93		1993/94		1994/95		1995/96		1991/92		1992/93		1993/94		1994/95		1995/96	
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Spring harvest[1]:																				
Dry weights (t/ha)	p=0.0133		p=0.2902		p=0.0359		p=0.0015		p=0.1450		p=0.0027		p=0.0112		p=0.0005		p=0.2873		p=0.0001	
Fall rye	5.19	1.05 b	6.37	1.21	2.73	0.64 b	5.67	0.55 c	6.46	2.33	3.98	1.06 c	3.60	1.11 ab	2.81	0.68 c	4.26	0.84	5.51	0.41 b
Winter wheat	7.44	2.08 a	6.80	1.64	5.79	1.25 a	9.90	1.08 a	9.43	3.08	6.79	1.93 b	2.17	0.55 b	4.85	1.02 b	5.63	0.98	4.76	1.14 bc
Annual ryegrass	8.89	0.61 a	5.71	0.83	5.11	1.51 a	8.12	1.81 b	7.40	1.77	6.84	0.90 b	4.54	1.32 a	4.24	0.70 b	5.18	1.97	10.8	0.64 a
Spring wheat	WK*		5.27	1.13	WK		WK		WK		9.11	2.08 a	4.85	0.96 a	6.71	0.89 a	5.54	1.08	5.45	0.32 b
Spring barley	WK		WK		WK		WK		WK		WK		WK		WK		WK		3.92	1.37 c
N concentration (%N)	p=0.0274		p=0.0162		p=0.0169		p=0.0013		p=0.0039		p=0.0863		p=0.0005		p=0.0020		p=0.0003		p=0.0002	
Fall rye	1.63	0.09 a	1.07	0.12 ab	1.13	0.05 a	1.30	0.15 a	1.10	0.09 a	1.38	0.06	1.20	0.08 a	1.12	0.03 a	1.20	0.08 a	1.00	0.13 b
Winter wheat	1.43	0.13 a	0.96	0.06 b	1.02	0.10 ab	0.93	0.05 b	0.75	0.06 b	1.15	0.08	1.13	0.05 ab	0.95	0.08 b	0.89	0.14 c	0.91	0.14 bc
Annual ryegrass	1.52	0.14 ab	1.16	0.11 a	0.90	0.08 b	0.98	0.03 b	0.85	0.07 b	1.31	0.15	1.02	0.09 b	0.90	0.01 b	0.94	0.04 bc	0.80	0.02 c
Spring wheat	WK		1.11	0.18 a	WK		WK		WK		1.21	0.13	0.86	0.07 c	0.83	0.10 b	1.01	0.08 b	0.91	0.14 bc
Spring barley	WK		WK		WK		WK		WK		WK		WK		WK		WK		1.20	0.08 a
N content (kg/ha)	p=0.0161		p=0.4217		p=0.0543		p=0.1077		p=0.6707		p=0.0088		p=0.0322		p=.0215		p=0.7297		p=0.0001	
Fall rye	85.4	21.4 b	68.9	19.7	30.9	7.2	73.3	9.1	71.8	29.4	55.0	15.0 c	43.3	13.8 a	31.5	7.9 b	51.1	10.1	54.8	6.1 b
Winter wheat	107	32.9 ab	65.4	17.7	58.6	11.6	91.5	10.5	69.5	21.5	77.4	19.5 bc	24.5	7.40 b	46.2	11.9 ab	49.9	8.8	49.3	7.1 b
Annual ryegrass	136	20.2 a	66.1	12.0	46.8	16.7	78.9	15.7	62.1	10.4	89.5	16.9 ab	45.6	11.5 a	38.1	6.0 b	49.2	20.0	84.9	4.4 a
Spring wheat	WK		57.2	9.3	WK		WK		WK		111	29.5 a	42.0	9.8 a	55.3	7.8 a	55.6	8.9	49.3	7.1 b
Spring barley	WK		WK		WK		WK		WK		WK		WK		WK		WK		46.1	14.4 b

Table 5. Continued

March and April. Therefore, the amount of green manure available from late seeded cover crops is strongly dependent on the time available for spring growth prior to establishment of summer crops.

3.4 Residual soil nitrate conservation

Cover crop N content was also determined in our screening trials (Table 5). The relative N content rankings closely followed the rankings for biomass production (Table 5). Perhaps the first impression gained from the cover crop N uptake data is the large year to year variability. For example, August seeded annual ryegrass, one of the better N accumulators, took up well over 100 kg N ha^{-1} in two years, but dropped to as little as 26 kg N ha^{-1} in 1994-95. Soil moisture was quite low in August 1994 and the annual ryegrass emergence suffered more from this than the larger seeded cereals. Maximizing cover crop uptake of residual NO_3 in the fall requires successful establishment and a long period of good growing conditions prior to December when cold temperatures and low light availability reduce crop growth and N uptake to negligible levels. South coastal BC has more than enough winter rainfall to completely leach any remaining NO_3 prior to the onset of the spring growth period (Bomke et al., 1994).

Spring cereals seeded prior to September are usually winter killed and their capability of capturing residual NO_3 is minimal when temperatures approach freezing. However, spring barley and wheat can take up substantial residual N, if they have a long enough growth period prior to frost. Also significant is that N concentration at the time of winter-kill usually exceeds 20 g kg^{-1} (2%), the minimum level required for decomposition without immobilizing soil N during the following growing season. The result is that the cover crop N mineralizes when soil temperatures warm in the spring often giving substantially higher available N for crops following winter-killed cereals than over-wintering cover crops (Nafuma, 1998). The latter continue growth under the low soil N conditions that are common following the winter rains.

If cover crop seeding must wait until late September, spring barley is less effective, < 50kg N ha^{-1}, in capturing and retaining residual N. Late planted spring wheat is more winter hardy and continues to take up N even following frost if satisfactory growing conditions persist. This occurred during the warm December of the 1991-92 winter. Usually spring wheat, when planted late, behaves like winter cereals, recommencing growth in the spring under low soil N conditions and having crop N concentrations well below the 20 g kg^{-1} minimum required to prevent soil N immobilization. When the over-wintering cover crops were planted in late August there were no significant differences in crop N content except in spring 1992 (Table 5). The potential for growth and N uptake was high during the fall of 1991 and at the spring harvest annual ryegrass contained more N than fall rye but was similar to winter wheat.

Cover crops planted in the third week of September differed significantly in N content the following spring prior to plow-down, except in 1994-95 (Table 5). While differences usually were not large, winter wheat, annual ryegrass and spring wheat were most effective at retaining N over winter, especially in 1991-92, while fall rye was often in the group of crops that contained the least N content by spring plow down time. For both the early and late plantings, such results are also reflected in the fall versus spring harvest ratios and differences with respect to biomass, N concentration and content (Table 6). For the rapidly establishing and relatively more cold tolerant fall rye, its fall/spring harvest biomass and N content ratios were greater than the other over-wintering cover crops except in 1995-96.

	Early planted[1]: approximately the third week of August.										Late planted[1]: approxi		
Year*:	1991/92		1992/93		1993/94		1994/95		1995/96		1991/92		1992/
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
Fall vs. spring harvest ratios[1]:													
Dry weights	p=0.0380		p=0.0290		p=0.0700		p=0.0039		p=0.1172		p=0.1055		p=0.03
Fall rye	0.69	0.16 a**	0.26	0.03 a	0.50	0.21	0.43	0.13 a	0.72	0.30	0.25	0.14	0.24
Winter wheat	0.38	0.12 b	0.15	0.05 b	0.26	0.15	0.18	0.01 b	0.33	0.12	0.11	0.07	0.15
Annual ryegrass	0.46	0.13 b	0.25	0.05 a	0.44	0.14	0.13	0.09 b	0.67	0.26	0.08	0.03	0.08
Spring wheat	n/a #		0.22	0.11 ab	n/a		n/a		n/a		0.13	0.02	0.06
Spring barley	n/a		n/a		n/a		n/a		n/a		n/a		n/a
Nitrogen concentration	p=0.2389		p=0.0036		p=0.0234		p=0.0001		p=0.1110		p=0.0782		p=0.00
Fall rye	1.60	0.28	2.82	0.71 b	1.99	0.20 b	2.03	0.23 c	2.38	0.25	3.34	0.41	3.24
Winter wheat	1.92	0.27	3.67	0.41 a	2.73	0.34 a	3.52	0.26 a	3.66	0.86	3.96	0.35	2.79
Annual ryegrass	1.82	0.20	2.81	0.44 b	2.44	0.11 ab	2.85	0.27 b	3.54	0.71	3.62	0.35	4.23
Spring wheat	n/a		3.48	0.74 a	n/a		n/a		n/a		3.90	0.35	5.31
Spring barley	n/a		n/a		n/a		n/a		n/a		n/a		n/a
Nitrogen content	p=0.1632		p=0.2141		p=0.2340		p=0.0297		p=0.2088		p=0.1159		p=0.03
Fall rye	1.09	0.22	0.72	0.12	0.97	0.39	0.86	0.22 a	1.76	0.94	0.80	0.36	0.74
Winter wheat	0.73	0.26	0.54	0.13	0.73	0.43	0.64	0.09 ab	1.25	0.59	0.43	0.25	0.41
Annual ryegrass	0.84	0.29	0.70	0.11	1.08	0.37	0.36	0.22 b	2.28	0.65	0.30	0.05	0.32
Spring wheat	n/a		0.72	0.24	n/a		n/a		n/a		0.50	0.14	0.29
Spring barley	n/a		n/a		n/a		n/a		n/a		n/a		n/a

[1]See Table 1 for planting and harvest dates.
#n/a: spring harvest cover crop either winter kill or there was insufficient sample to harvest in the fall (height les
*1995/96 late planted cover crops were not harvested in the fall; see Table 5.
**Means in the same column followed by the same letter are not significantly different; alpha=0.05.

Table 6. Selected early and late planted cover crops fall vs. spring harvests ratios and differences for
weight, nitrogen concentration and content.

Year*:	Early planted[1]: approximately the third week of August.										Late planted[1]: approximately the third week of September							
	1991/92		1992/93		1993/94		1994/95		1995/96		1991/92		1992/93		1993/94		1994/95	
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Fall vs. spring harvest differences[1]:																		
Dry weights	p=0.0127		p=0.0829		p=0.0342		p=0.0016		p=0.0850		p=0.0038		p=0.0134		p=0.0007		p=0.0325	
Fall rye	1.58	0.81 b	4.69	0.77	1.43	0.77 b	3.29	1.01 b	2.29	2.06	3.04	1.06 b	2.82	1.28 bc	2.22	0.61 c	2.69	1.38 b
Winter wheat	4.73	1.82 a	5.73	1.07	4.24	1.16 a	8.10	0.99 a	6.56	3.13	6.11	2.02 a	1.85	0.09 c	4.42	1.06 b	n/a	
Annual ryegrass	4.88	1.41 a	4.28	0.79	3.03	1.69 ab	7.15	2.21 a	2.70	2.33	6.27	0.83 a	4.22	1.34 ab	3.96	0.73 b	n/a	
Spring wheat	n/a		n/a		n/a		n/a		n/a		7.97	1.86 a	4.60	0.96 a	6.21	0.93 a	4.50	0.87 a
Spring barley	n/a		n/a		n/a		n/a		n/a		n/a		n/a		n/a		n/a	
Nitrogen concentration	p=0.3790		p=0.0243		p=0.0110		p=0.0001		p=0.2949		p=0.7615		p=0.0030		p=0.0032		p=0.0197	
Fall rye	0.97	0.46	1.90	0.58 b	1.12	0.21 b	1.32	0.24 c	1.51	0.27	3.23	0.62	2.68	0.49 bc	3.40	0.39 b	1.87	0.34 b
Winter wheat	1.30	0.29	2.54	0.34 a	1.74	0.25 a	2.32	0.11 a	1.96	0.58	3.40	0.33	2.03	0.75 c	3.40	0.53 b	n/a	
Annual ryegrass	1.22	0.20	2.06	0.33 b	1.30	0.04 b	1.80	0.22 b	2.12	0.42	3.38	0.17	3.28	0.20 ab	4.57	0.12 a	n/a	
Spring wheat	n/a		n/a		n/a		n/a		n/a		3.48	0.17	3.70	0.13 a	4.40	0.39 a	2.75	0.34 a
Spring barley	n/a		n/a		n/a		n/a		n/a		n/a		n/a		n/a		n/a	
Nitrogen content	p=0.1173		p=0.2913		p=0.2513		p=0.0550		p=0.0791		p=0.0268		p=0.0808		p=0.0397		p=0.3802	
Fall rye	-7.53	15.3	20.0	10.2	1.89	10.6	12.0	15.5	-38.5	33.3	13.2	17.1 b	14.0	18.2	4.30	8.8 b	3.5	24.9
Winter wheat	31.8	30.5	28.7	4.6	15.7	25.9	33.2	10.3	-7.90	37.3	46.7	25.6 a	14.5	24.9	27.7	15.0 a	n/a	
Annual ryegrass	26.5	37.6	20.4	9.2	1.08	18.9	52.3	26.1	-76.2	28.2	62.7	10.4 a	32.0	13.0	22.8	7.8 a	n/a	
Spring wheat	n/a		n/a		n/a		n/a		n/a		57.8	25.7 a	30.6	10.6	29.3	7.5 a	16.0	8.3
Spring barley	n/a		n/a		n/a		n/a		n/a		n/a		n/a		n/a		n/a	

Table 6. Continued

Furthermore, as discussed above, the fall rye biomass and N content differences were always amongst the least relative to the other mentioned over-wintering cover crops, particularly for the late plantings. Therefore, both harvest ratios and differences between spring and fall values suggest that for fall rye a greater proportion of its cumulative biomass and N content is accumulated in the fall, whereas a greater proportion of the biomass and N contents for the other over-wintering cover crops resulted during spring growth. This was particularly evident with the late planted cover crops' N content ratios and differences, where the fall rye N content ratios were highest and differences much less. These results suggest that while the fall rye was particularly effective in N uptake during the fall, its ability to retain such N is less than other cover crops, such as winter wheat, annual ryegrass and spring wheat. Such results could be related to the fall rye losing a relatively greater amount of biomass over the winter via the loss of older shoots or tillers.

Early planted cover crops usually captured more residual N than when planted late. Nitrogen uptake often exceeded 75 kg ha^{-1} for cover crops planted in August as compared to an average closer to 50 kg ha^{-1} for most of the crops when planted in the third week of September. Cover crops cannot be relied upon to prevent NO_3 leaching if N additions to the previous crop are greatly in excess of crop needs or if the cover crop growth potential prior to winter is low. With appropriate fertilizer rates applied to the previous cash crop, the cover crops can reduce soil residual NO_3 to low levels and, over the longer term prevent the loss of substantial quantities of soil N. Preventing leaching losses of 500 to 750 kg N ha^{-1} during a decade of cover cropping will result in substantially higher mineralizable soil N and reduced fertilizer requirements. The soils upon which our experiments were conducted contain between 2000 and 4000 kg ha^{-1} of total N, most of which is stable and does not enter the pool of available N. Forms of N that are readily mineralized into available N for summer crops are dominated by fresh crop residue N such as that which is retained by a sustained cover cropping program.

The problem of short-term immobilization of available soil N by a decomposing cover crop is of concern. Any non-leguminous cover crop that is allowed to grow during the spring in south coastal BC will have low N concentrations by plow-down and will reduce short term N availability to the subsequent crop. The farmer may compensate for this by:

- killing the cover crop early (and losing some of the green manure value of the cover crop);
- increasing external N inputs (e.g. fertilizers or manures); or
- adding a legume to the over-winter cover crop and using biological N fixation during the spring growth period to increase the concentration of N in the cover crop (Odhiambo & Bomke, 2000).

4. Conclusions

Relative to the cover crops screened, fall rye, annual ryegrass, winter wheat, spring wheat and spring barley performed the best. Planting cover crops early (late August) consistently gave two to four times higher biomass yields prior to winter than the late-planted (late September) cover crops and spring cereals often produced greater biomass than other cover crops. Early seeded spring cereals usually winter-killed and produced between 3 and 5 t ha^{-1} of dead mulch material; while early-seeded, over-wintering cover crops produced 5 to 8 t ha^{-1} of green manure in the spring. Late-seeded, over-wintering cover crops produced 4 to 6 t ha^{-1} of green manure with 'Max' spring wheat over-wintering and performing consistently well. With respect to residual soil nitrate conservation, comparisons of relative N contents (rankings) closely followed those for biomass yields. Delaying cover crop seeding until late September reduced the uptake of residual soil N. All late seeded cover crops took up less than 60 kg ha^{-1} of N prior to winter, but the performance of each cover crop varied greatly among years.

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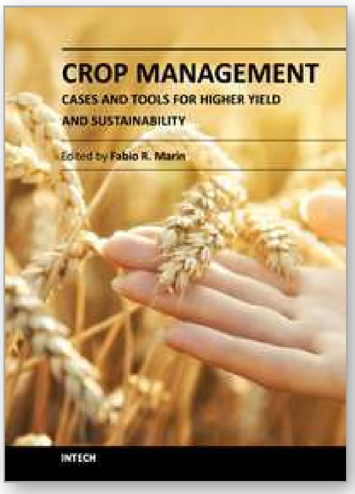

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Agricultural production is related to physical constrains, which may not always be overcomed by technology. However, under the same conditions, it is possible to see well-managed farms consistently making greater profits than similarly structured, neighboring farms. For each abiotical condition, it is well-known there is a difference between the potential and observed yields, which is usually high and often could be reduced through more appropriate management techniques. In this book, we have a selection of agricultural problems encountered in different regions of the world which were addressed using creative solution, offering new approaches for well-known techniques and new tools for old problems.