Soil science on the Canadian prairies – Peering into the future from a century ago

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Janzen, H. H. 2001. **Soil science on the Canadian prairies – Peering into the future from a century ago**. Can. J. Soil Sci. **81**: 489–503. Now, as a new century begins, may be a good time to reflect on the future of Soil Science on the Canadian prairies. One way to do that is to step back about one hundred years, to the turn of the previous century when our grassland soils were first cultivated. What questions perplexed scientists then? And how did they look for answers? My objective is to listen for our forebears' thoughts in their writings, now largely buried. From this historical vantage may emerge insights, not only into where our science has been, but also into where it might yet go.

Key words: Soil organic matter, crop rotation, grassland soils, history

Janzen, H. H. 2001. **Les sciences du sol dans les prairies – évolution depuis un siècle**. Can. J. Soil Sci. **81**: 489–503. Puisqu'un nouveau siècle commence, peut-être vaudrait-il la peine de jeter un œil sur l'avenir des sciences du sol dans les Prairies canadiennes. Une façon de le faire est de remonter dans le temps d'une centaine d'années, au tournant du XX^{e} siècle, quand les prairies ont commencé à être cultivées. Quelles questions se sont posé les chercheurs de l'époque? Comment leur ont-ils trouvé une réponse? Mon but est de sonder leur esprit à travers ce qu'ils ont écrit, textes largement sombrés dans l'oubli aujourd'hui. De ce point de vue historique, nous pourrions tirer des enseignements non seulement sur le chemin que la science a parcouru depuis, mais aussi sur ce que l'avenir réserve à cette dernière.

Mots clés: Matière organique du sol, assolement, sols des prairies, historique

A few years ago, John Horgan riled some scientists with his book "The End of Science"[1]. He proposed that we are "Facing the limits of knowledge in the twilight of the scientific age"; that scientists, in the words of Bentley Glass, "are like the explorers of a great continent who have penetrated to its margins in most points of the compass and have mapped the major mountain chains and rivers. There are still innumerable details to fill in, but the endless horizons no longer exist."[2] Each new increment of knowledge comes harder – it costs more and brings us closer to our cognitive limits. "When we peer down into the deepest recesses of matter or at the farthest edge of the universe," writes Horgan, "we see, finally, our own puzzled faces looking back at us."[3]

We want to eye cautiously any pronouncement that science is soon finished – similar dour views a century ago were swept away by Einstein, Hubble, Watson and Crick, among others.[4] But the question has merit: Are we, in our chosen science, still making advances? And, more to the point, how do we ensure that our work remains fresh, innovative, and relevant?

My objective is to ask those questions about Soil Science on the Canadian prairies. I admit that the answers are far beyond me – but I hope that even asking the questions will already stimulate collective thought.

And I hope to look at the questions from a historical perspective; I want to step back about a century, when our farming was still new and our science still young. What baffled and enticed scientists then? How did they attack the riddles of their day? Where possible, I present their original words, so that we can listen to their thoughts as they expressed them. Then, having sat among our forebears, I hope to peer from their vantage into our hazy future.

SOIL SCIENCE ON THE PRAIRIES A CENTURY AGO

The history of prairie agriculture is unusual because the farmer and the scientist[5] arrived together. When the plows began in earnest to invert the prairie sod, scientists were already there to record the effects. And from the outset, preserving the soils was a priority. W. M. Saunders, Director of Experimental Farms, wrote in 1893 that, among the productivity factors controlled by farmers, "none is more important than the maintenance of the fertility of the soil which is the chief aim of all good farming and on which a continuance of good crops mainly depends. In the soil, a large store of fertility has been laid up…, which may … be continually added to and improved, but by careless and injudicious management may be prodigally wasted…"[6].

Early Analyses of Soil Organic Matter

Early on, scientists recognized how important organic matter was for soil fertility. In 1910, Frank Shutt, Dominion Chemist, described three "functions of humus", not unlike those we might list today. He said it is "nature's storehouse for nitrogen" and other nutrients; that it has favourable "influence on the physical condition of the soil"; and that "a distinct relationship exists between organic matter and the

Table 1. Examples of organic matter analyses conducted on prairie soils in the 19th century

Location	Year[z] sampled	%N	%OM (or %C)	Source and comments
1 Portage la Prairie	1882	0.247		Lawes, J.B. and Gilbert, J.H. (1885). On some points in the composition of soils; with results illustrating the sources of fertility of Manitoba prairie soils. J. Chemical Society vol. XLVII, 380–422. Soils were uncultivated, or cultivated for only a few years. Sampling depth: "surface" or "1 to 12 inches".
2 Saskatchewan district	1882	0.303		
3 Fort Ellice	1882	0.250		
4 Niverville	1883	0.261	(3.42)	
5 Brandon	1883	0.187	(2.66)	
6 Selkirk	1883	0.618	(7.58)	
7 Winnipeg	1883	0.428	(5.21)	
8 Maple Creek (a)	1889	0.125	5.16	Shutt, F.T. 1890. In Experimental Farms Reports for 1889. Brown Chamberlain, Ottawa. p. 43. Uncultivated.
9 Maple Creek (b)	1889	0.114	5.57	
10 Walsh Flats (a)	1890	0.140	4.95	Shutt, F.T. 1891. in Experimental Farms Reports for 1890, Brown Chamberlain, Ottawa. p. 108.
11 Walsh Flats (b)	1890	0.135	5.28	
12 Tilley (a)	1890	0.179	4.66	
13 Tilley (b)	1890	0.389	10.87	
14 Vermillion Hills (a)	1890	0.346	10.20	
15 Vermillion Hills (b)	1890	0.159	4.42	
16 Yorkton	1891	0.477	13.27	Shutt, F.T. (1892). in Experimental Farms Reports for 1891, S.E. Dawson, Ottawa. p. 157. sampling depth: not stated, though presumably "surface". %OM is referred to as "organic and volatile matter". Uncultivated.
17 Saltcoats	1891	0.538	12.74	
18 Moosomin	1891	0.454	11.18	
19 Calgary	1891	0.425	11.63	
20 Brandon	1891	0.281	8.55	
21 Yorkton	1897	0.501	14.01	Shutt, F.T. (1898). in Experimental Farms Reports for 1897, S.E. Dawson, Ottawa. p. 164. Sampling depth: "surface". %OM values referred to as "loss on ignition". Uncultivated.
22 Saltcoats	1897	0.571	13.54	
23 Moosomin	1897	0.479	11.79	
24 Calgary	1897	0.447	12.23	
25 Tilley	1897	0.398	11.13	
26 Vermillion Hills	1897	0.354	10.43	
27 Red River Valley	1897	1.005	26.29	

[z]Sampling date given for soils 10–27 is the date of reporting; actual sampling date may be earlier.

bacterial life of the soil"[7]. Detailed analysis of organic matter and nitrogen in prairie soils was therefore already underway in the nineteenth century.

Among the first to look at organic matter in prairie soils were J.B. Lawes and J.H. Gilbert, founders of the Rothamsted Experimental Farm (Table 1). In 1882, they acquired three soil samples, from a set of 40 to 50 taken between Winnipeg and the Rocky Mountains, and found that "these soils are probably about twice as rich in nitrogen as the average of arable soils in Great Britain."[8] Soon they visited the Canadian prairies themselves: "In a short visit paid by one of us to Manitoba in the autumn of 1882, a few samples of soil were collected for examination"[8]. Regrettably, these samples apparently never arrived at their Rothamsted laboratory: "notwithstanding the infallible baggage-cheque system of the American continent, the bag containing the samples was lost…"[8]. But Lawes and Gilbert were not deterred. At a Canadian Pacific Railway exhibit at London in 1883, they located four-foot soil cores from Manitoba and set about detailed analysis. The soils, in the surface foot, contained as much as 0.62% N and 7.6% C (Table 1), concentrations several-fold those observed at Rothamsted.

Canadian officials, too, were interested in the composition of prairie soils. In 1889, Shutt analyzed soils from Maple Creek, North-West Territories and, observing their high nitrogen content (Table 1), concluded that "If … future analyses bear out [these results], we shall have scientific data to support the statements regarding the great fertility of North-West soils, and their peculiar suitableness for the growth of cereals."[9] The next year, he reported analyses of soils from several regions that "enjoy but a very limited rainfall, and hence have yielded poor crops" to see if crop growth was constrained by soil properties.[10] Organic matter content ranged from 5 to 11%, and nitrogen from 0.14 to 0.39%. Analysis of virgin soils a few years later showed even higher concentrations, and demonstrated "their high nitrogen content and the large amounts of organic matter that are almost invariably present"[11].

These analyses of organic matter, then, confirmed the "richness" of the native prairie soils, and lent some credence to optimistic views like those of Macoun who, in 1882, talked about some prairie soils having "almost inexhaustible fertility"[12]. Shutt, in 1910, wrote of the prairie soils in almost reverential tones: "we may now inquire briefly as to the cause of the richness of these prairie soils. The answer is simple… It is due to the tremendous accumulation of nitrogenous organic matter with its associated mineral constituents – the remains of countless generations of plant life – for, since the glacial period practically, these prairies have been continuously clothed with grasses and leguminous herbage"[13].

But already the reverence was tinged with foreboding: "the great depth and high fertility of the prairie soils come to us as an accumulated legacy … one which, looking to the future prosperity of the west, we shall do well to conserve by rational methods of farming."[13]

Table 2. Losses of nitrogen during initial decades of cultivating Saskatchewan soils

Site	Nitrogen content (pounds/acre)		% loss	Years cultivated
	virgin	cultivated		
1. Indian Head[z]	6 936	4 730	32	22
2. Melfort[y]	12 300	11 480	7	29
3. Kinistino[y]	14 420	11 500	20	34
4. Rosthern[y]	8 800	6 360	28	ND
5. Yorkton[y]	10 800	9 740	10	31
6. Regina[y]	6 800	5 980	12	12
7. Indian Head[y]	9 100	3 960	56	30

[z]Site 1 data reported by Shutt, F.T. 1906. in Experimental Farms Reports for 1905, S.E. Dawson, Ottawa, p. 128. Values reported are for the surface 8 inches of soil. The author also reports data for the surface 4 inches of soil, where losses amount to 37% of that in the virgin soil.
[y]Data for sites 2 to 7 are from Hansen, R. 1921, The soil. pp. 33–77 *in* Bracken, John. Dry Farming in Western Canada. The Grain Grower's Guide, Limited. Winnipeg, Canada. 386 pp. Nitrogen contents were reported in units of pounds nitrogen per 2 000 000 pounds soil (0 – 6 2/3 inches).

First Indications of Organic Matter Loss

Even as the first analyses were confirming the rich organic matter reserves of prairie soils, some scientists were already uneasy about their fragility. Among the first to voice concern were Lawes and Gilbert. They measured nitrogen mineralization in the Manitoba soils in a year-long incubation and observed "how freely these soils will yield up their nitrogen in an available form, when subjected to favourable conditions…"[14]. But rather than only marveling at the high fertility (as I might have), they foresaw a danger: "It must be borne in mind, however, that this ready susceptibility to oxidation of the nitrogen is a source of loss rather than of gain, if the nitrates are not taken up by crops… "[14].

Thus, Lawes and Gilbert were among the first to warn of organic matter and fertility loss in prairie soils. They allowed that "in the early years of settlement, … the burning of the straw, and the deficient production, or the disregard and waste, of manure, are more or less unavoidable, but nevertheless very exhausting practices"[14]. "Still," they warned, "the fact should not be lost sight of, that such practices of early settlement do involve a serious waste of fertility."[14] Others, too, worried about depletion of organic matter; "Soils in which grain is grown year after year lose, it is stated, much nitrogen by [the] oxidation of humus" wrote Saunders and Shutt in 1902.[15]

And the losses feared were soon borne out by analysis. In 1905, Shutt sampled a site at Indian Head, Saskatchewan, which had been cultivated for 22 yr and compared its N content to that of an adjacent "native" site. The cultivated soil had lost about 2200 lbs of N acre^{-1} in the surface 8 inches, about 32% of that originally there (Table 2).[16] Of the N lost, only about one-third had been extracted by crops.

Two years later, Alway and Trumbull, two American scientists, traveled to Indian Head to sample soils from various long-term treatments because "Investigations in dry-land-farming on the Great Plains have been undertaken only so recently … in the United States that data are not yet available to indicate how serious the nitrogen problem is, how soon it will become acute, or how best to solve it."[17] Based on analysis of a wide range of treatments, they concluded that, in the worst case (continuous bare cultivation), "The extreme loss of nitrogen, humus, and organic carbon in 25 years is about one-third of the amounts originally present in the prairie."[17] (Table 3).

Hansen, of the University of Saskatchewan, reported that six Saskatchewan soils, cultivated for 12 to 34 years, had lost between 7 and 56% (mean = 22%) of the nitrogen in the surface 17 cm of soils (Table 2).[18] He cautioned, however, (with counsel sometimes overlooked today) that "the figures … are not to be taken at their absolute value … [because] we cannot be certain that a sample of soil from cropped land had at one time the same composition as a sample of virgin land adjoining."[18]

Measurements almost 100 years ago, then, though not without shortcomings, suggested that cultivated soils had already lost about 20 to 30% of the organic matter in the plow layer, a value remarkably similar to our current best estimates. [19]

Causes of organic matter loss

What caused the sudden, serious loss of soil organic matter? Ironically, much of the early blame fell on the practice that seemed to have rescued prairie farming in the first place: the fallow-wheat system.

Table 3. Losses of carbon, humus, and nitrogen during initial decades of cultivation at Indian Head (Alway, F. J. and Trumbull, R. S. 1910. A contribution to our knowledge of the nitrogen problem under dry farming. Journal of Industrial and Engineering Chemistry 2: 135-138.) Sampling depth = 6 inches

No. of samples	Cultivation history	Humus[z] (%)	Total N (%)	Organic C[y] (%)
6	Virgin prairie	2.84	0.384	4.20
2	Cultivated 7 yr; grass 18 yr	2.75	0.384	4.05
2	Cultivated 16 yr; grass 9 yr	2.46	0.367	3.82
2	Cultivated 21 yr; grass 4 yr	2.25	0.303	2.10
22	Cultivated 25 yr (rotation plots)	2.01	0.266	2.68
6	Tree strips; ordinary cultivation 10 yr, bare cultivation 15 yr	2.12	0.274	2.84
6	Cultivated; adjacent to tree strip	2.34	0.326	3.35

[z]"Humus" was "determined by the Hilgard method".
[y]Organic C was determined "by combustion with copper oxide after the carbonates had been decomposed by treatment with phosphoric acid".

Summer fallow was not a new invention – Vergil referred to its use in ancient Roman times.[20] And in western Canada, early Selkirk settlers in the Red River Valley already knew its advantages.[21] But the prominence of fallow in prairie agriculture originates from a fortuitous observation in the Qu'Appelle Valley of Saskatchewan. In 1885, during the Riel Rebellion, some settlers and their teams were hired for military transport and, consequently, not all of the cultivated land was seeded. The next year was very dry so that "two thirds of the grain in the country was ploughed up and the remainder gave yields of from three to five bushels per acre"[22]. But, as one settler reported, "the yield on the summerfallowed land averaged 26 bushels per acre and was such an object lesson in that driest [of] dry years, that no one who saw the crop could mistake the value of this method of cultivation"[22]. This settler, Angus MacKay, later became superintendent of the Experimental Farm at Indian Head, where he soon formalized and advocated the regular use of fallow in prairie farming systems.[23]

But even MacKay admitted to growing worries about long-term effect of regular fallows, as seen in this progression of views:

1889: "It is quite within the bounds of possibility that some other and perhaps more successful method may be found, but, at present, I submit that 'fallowing' the land is the best preparation to ensure a crop."[24]

1894: "In no year has the beneficial effect of fallowing been so apparent … as during the past season. …Fallow-land … proved, as it always has done, to be the only safe way of growing grain in this country."[25]

1901: "It is very gratifying to know that throughout the Territories, summer-fallowing is rapidly becoming general."[26]

1909: "Among the disadvantages [of summer fallow] are: the liability of the soil to drift, the over-production of straw in a wet season … and it is claimed the exhaustion of the soil."[27]

1914: "[T]hat there must be a change in the system of cropping is admitted by all up-to-date farmers, for the growing of wheat alone and summerfallowing every third year, is too favourable to the introduction of weeds, the exhaustion of the soil fibre, and the depletion of fertility."[28]

Thus, while still insisting that summer fallow was necessary, even MacKay, the "Apostle of the Summer Fallow"[29], conceded that fallow might eventually harm soil productivity.

Others were not as reticent. "[T]here has been a considerable reduction in the percentages of organic matter and nitrogen, consequent upon cultivation", wrote Shutt in 1910.[30] "This loss… has in a very large measure been due to fallowing – a system of immense value for the conservation of moisture and the freeing of the land from weeds, but one particularly wasteful as regards organic matter and nitrogen." Added James Murray of Brandon in 1911: "The continued cultivation and exposure of the soil to sun and air by summerfallowing has had the effect of working the fibre out of the soil and depleting the humus, thus making it much more liable to blow, more difficult to work, and less congenial to growing plants."[31] Bracken, a University of Saskatchewan professor, conceded that "The fallow is immediately profitable" but averred that "we must find a substitute for it or pay the cost in the wasting of permanent 'fertility'"[32].

Summer fallow was, admittedly, only one facet of early cropping systems that led to organic matter loss. As recognized even then, the broader reason for organic matter loss was, in the words of Murray, "The continual removal of grain crops from the land with nothing added to counteract the effect."[33] Shutt, with typical candor, said: "We have been terribly wasteful of plant food, especially in the Northwest, where farming has been likened to mining."[34] Summer fallow was perhaps only the most visible feature of a farming system that lost more organic matter and nutrients than it returned.

The direct loss of organic matter under fallow-grain farming was worrisome enough, but soon it led to another, even more serious threat to crop yields – soil drifting. Wrote Shutt, in 1910: "It must now be stated that a further loss may result from fallowing…: the removal of … the rich surface soil by erosion and drifting. The constant cultivation of the land breaks up the fibre – the binding element which gives the toughness to the prairie sod."[35] "Continued summer-fallowing, while it gives good crops for a long time, must in the end be exhaustive of the fertility of the land and destructive of the vegetable fibre which holds the land in place and prevents blowing", warned a government report in 1912.[36] A Royal Commission, investigating the economic disaster unfolding in southern Saskatchewan farms, concluded "when the root fibres of the native prairie plants had been worked out or destroyed by frequent plowing and cultivating, the land developed a tendency to blow and drift"[37] Thus, loss of the organic matter that held prairie soils in place, precipitated further, sometimes devastating escalation of soil loss. Reported Seager Wheeler, a champion wheat grower: "In many fields nearly all the top soil has blown away, leaving only the bare subsoil. [The losses are] mainly due to a lack of fibre that is essential to bind the soil grains together."[38] And the solution? "Increasing the organic matter content," wrote Bracken, " … is the chief and probably the most permanent means of lessening the danger of soil drifting."[39]

The Search for "Permanence"

The continued depletion of organic matter, compounded by erosion, led scientists about a century ago to predict that farming practices could not be sustained long – in their words, this agriculture was not "permanent".[40] One of the most eloquent in expressing this view was Bracken: "If a system of permanent agriculture is to be established on our western prairies – and our future welfare depends upon its establishment – we must not carry our wheat system too far. We cannot waste the fertility of our soil and still have it."[41] "The problem of the future", he said, "lies in finding for each soil and climatic zone the system that is at once the most profitable and the most permanent."[42]

What was the answer? Shutt proposed in 1910 that "exclusive grain growing and fallowing, now so common,

Table 4. Crop rotations on the prairies underway in 1912 (Grisdale, J. H. 1912. Experimental Farms Reports for the Year Ending March 31 1912. C. H. Parmlee, Ottawa. p. 27)

Name	Yr	Sequence[z]	Remarks[y]	Locations[x]
A	1	Wheat each year		All
B	2	Fallow-wheat	Originally winter wheat	Le
C	3	Fallow-wheat-wheat or coarse grain	Spring or winter wheat	IH, R, S, La, Le
D	4	Wheat-wheat-oat or barley-fallow	Manure in year 2	B
E	4	Wheat-wheat-oat or barley-fallow	No manure	B
F	5	Wheat-wheat-corn-oat or barley-clover hay		B
G	6	Wheat-wheat-oat or barley-clover hay-past-corn		B
H	6	Wheat-wheat-fallow-oat-clover hay-past	Manure in year 6	B
I	6	Flax-oat-fallow-wheat-clover hay-past		B
J	6	Fallow-wheat-wheat-oat-hay-past		IH, R, S
K	6	Hoed crop-wheat-oat-hay-past-past	Manure in year 4	La
L	6	Hay-past-past-wheat-oat-barley		La
M	6	Fallow-wheat-oat-fallow-pea/oat hay-barley or oat		Le
N	7	Alf-alf-alf-alf-alf-grain-grain		La
O	7	Hoed crop-wheat-oat-fallow-barley-hay-past		La
P	8	Fallow-wheat-wheat-fallow-corn-barley-hay-past	Manure in yr 5	IH, R, S
Q	8	Roots-wheat-hay-hay-past-past-past-rape	"Sheep rotation"	B
R	9	Fallow-hoed crop-wheat-oat-fallow-wheat-oat-hay-past	Manure in year 2	IH, R, S, Le
S	9	Fallow-hoed crop-wheat-fallow-wheat-oat-fallow-pea/oat hay-past	Manure in yr 7	Le
T	10	Fallow-wheat-oat-alf-alf-alf-alf-fallow-hoed crop-wheat	Alf seeded in 21 in. rows; manure in yr 10	Le
U	10	Alf-alf-alf-alf-alf-alf-hoed crop-wheat-wheat-oat	Irrigated	Le
V	10	Alf continuously	Irrigated	Le
W	10	Wheat-wheat-corn-oat-barley-alf-alf-alf-alf-alf		B

[z]Abbreviations are as follows: past = pasture, alf = alfalfa; hay crops were usually underseeded in previous cereal crop; hay and pasture crops were typically legume/grass mixtures.
[y]Selected comments from Grisdale (1912). Not all manure amendments were recorded in his report. For example, Rotation U received regular manure applications.
[x]Abbreviations are as follows: B = Brandon, La = Lacombe, Le = Lethbridge, IH = Indian Head, R = Rosthern, S = Scott.

must give place to more rational farming methods if the soil is to be maintained at its present high standard of productiveness. …[T]he store of humus with its concomitant nitrogen must not be allowed to become depleted, and to this end the means are the adoption of a rotation, more particularly one containing a legume, and the keeping of live stock."[43] Murray, a year later, concurred: "The effect of continuous grain growing with little or nothing being returned to the soil must become more marked from year to year. … A solution of the problem lies in the adoption of a system of crop rotation, that will gradually year by year make the land more productive and at the same time enable the margin of profit to be increased."[44]

Thus, a prominent objective a hundred years ago was to find suitable, restorative crop rotations. The first rotation study in western Canada, evidently, was established in 1893 at Brandon. Reports S.A. Bedford, Superintendent of the Experimental Farm: "At present very few farmers in this country, practice a rotation of crops, many following wheat with wheat until the land is so impoverished or made foul with weeds, that less than half a crop is obtained. As this system, or rather want of system, will have to be changed before many years, some experiments were undertaken this year for the purpose of throwing light on the proper rotation for this country."[45]

Before long, detailed crop rotation studies had been established across Canada. The 1912 Experimental Farms report, for example, lists 12 Farms from Agassiz, BC, to Charlottetown, PEI, with rotation studies underway.[46] In the Prairie Provinces alone, there were experiments at six sites: Brandon, Indian Head, Rosthern, Scott, Lethbridge, and Lacombe. In all, they evaluated 23 rotations, many of them at more than one site. And each was assigned a consistent letter name; for example, rotation "A" was always "continuous wheat", Rotation "R" was a 9-yr rotation including grain, "hoed crop", hay, and pasture; and Rotation "U" was a 10-yr irrigated rotation with six years of alfalfa (Table 4).

Crop rotation studies were also a priority in the fledgling agricultural colleges. John Bracken refers to "forty rotations including perennial crops" and "120 rotations including only annual crops" established at the University of Saskatchewan, apparently in 1915.[47] At the Manitoba Agricultural College, the "Bedford" rotation (named after the Superintendent of the Brandon Experimental Farm and later Professor at the College[48]) was established in 1914, though it was soon discontinued because of demands for the land.[49]

The philosophy underlying these new rotations was to diversify farming by including livestock. As pointed out by McKillican at Brandon in 1913: "There is a growing sentiment … in favor of increasing the number of live stock kept, growing more forage crops, and thus going in for that system of agriculture, known as mixed farming… . The very essence of the advantage of mixed farming, is that it makes possible a more scientific rotation of crops than can be practised under grain growing."[50] A 1900 Manitoba report observed: "The sentiment that livestock forms the basis of all agricultural success now pervades the Province. This sentiment fully developed will bring on its tide of prosperity, natural fertilizers and rotation of crops, which will preserve the fertility of the soil…"[51]. A few years later, Bracken wrote: "No agricultural country has ever prospered for more than a generation or two that has not made provision for maintaining the nitrogen and organic matter content of the soil. … [L]egumes or grasses .. must be grown or annual crops must be plowed under if we are to maintain the organic matter of the soil. And if legume crops or grass crops are grown there must be live stock to dispose of them."[52] A Royal Commission in 1920 concluded that, even in the drought-prone soils of southwestern Saskatchewan, "a system of farm management in the southwest to be reasonably certain of success should be of a diversified character. … There must also be live stock of some kind to consume farm products."[53] Consequently, many of the new rotations under study early in the 20th century were designed to integrate livestock into the nutrient cycle.

And these diversified cropping systems appear to have maintained or even enhanced soil organic matter. Shutt analyzed soils sampled from the Brandon rotations in 1921 and compared N and organic matter concentrations to those in 1910 (Fig. 1). He wrote: "we may conclude that during the eleven-year period the nitrogen content of the soil … has been maintained and in certain instances materially increased in those rotations which included the growing of grasses and legumes with light dressings of manure".[54] Similar observations were also reported for other sites. These studies, while not without limitations, may qualify as the first "carbon sequestration" studies on the Canadian prairies.[55]

Early scientists held out much hope for the new diversified cropping systems. MacKay, already in 1894, implied that the days of strictly wheat farming were almost at end. "I am pleased to note the increased interest taken in dairy work throughout the country, as well as the large numbers going into mixed farming. Only in a few districts is wheat still 'king', while many are adding cattle, pigs, poultry, &c., to the farm work".[56] A report issued in 1912 proclaimed, optimistically, that "The importance of 'mixed' farming, in order to preserve the fertility of the soil is also becoming apparent, so that the raising of both beef and dairy cattle is likely to assume much greater prominence in the near future than it has held in the past."[57] Many assumed that the exploitative fallow-grain system was a "necessary evil"[58] soon to be supplanted by better systems after a brief pioneering phase. In a 1907 review of Saskatchewan agriculture, Honeyman wrote: "production of wheat in large quantities will be the chief object of the farmer in the newer districts; but with the exhaustion of soil fertility, the increase of weeds, and the opening of new markets… other things will be found more profitable than wheat…"[59]. Rutherford, Dean of the Saskatchewan College of Agriculture was even more visionary: "extensive wheat farming is only a passing stage", he reportedly said in 1914. " … wheat growing, like the bison, in the course of a few years will have to be protected and safeguarded in order to prevent its becoming extinct"[60].

But despite the early optimism – despite the conviction of scientists, based on solid data, that diversified systems would restore depleting organic matter – these new systems were never widely embraced. McKillican, writing about Manitoba agriculture in 1920, said: "The corner stone of dry farming … is the summerfallow and so it is likely to continue for many years."[61] And he was right: fallow accounted for 13% of Manitoba farmland in 1883–1889, and 26% in 1960–1969.[62] In 1922, L.E. Kirk of the University of Saskatchewan acknowledged that "The summer fallow has thus become the foundation of our cropping system and a good summerfallow is generally considered the best guarantee of a bountiful harvest."[63] Shutt himself reported gloomily in 1924 that "though recently, mixed farming … has been introduced…, grain growing … is still the predominating phase of typical prairie agriculture … . The agricultural future of the prairies as a wheat producing country would thus appear to be largely settled."[64] But he could not resist one last salvo: "Looking to the up-keep of soil fertility, grain growing as practised to-day on the prairies must be regarded as irrational; the teachings of agricultural science would pronounce it as wasteful, for it means destruction of organic matter and the carrying off of plant food with no attempt at any return."[65]

What happened? Early in the 20th century, scientists had already designed diversified systems, they had data to support their "permanence" and they were hopeful that these systems would soon be adopted. And yet, within two decades, it seemed clear that prairie soils were to be used mainly to grow grain, often after fallow. There may be many reasons why farmers did not embrace the diversified sys-

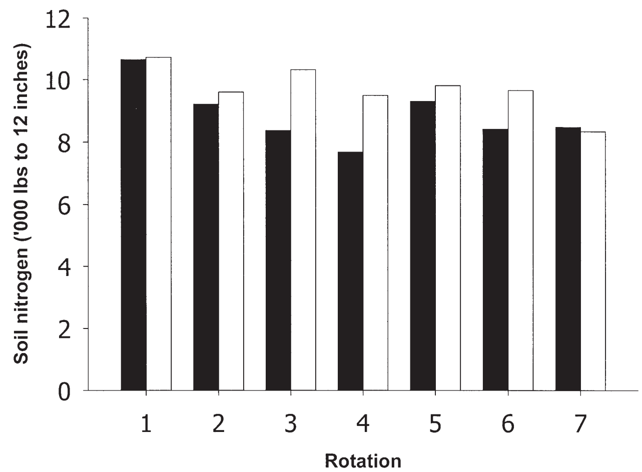

Fig. 1. Changes in soil N content of rotation plots in Brandon, 1910–1921. The author also reported soil organic matter contents. Rotations are as follows: 1. grain-grain-grain-hay-hay-hoed crop [+ manure]; 2. grain-grain [+ manure]-fallow-grain-hay-hay; 3. flax-grain-fallow-grain-hay-hay [+ manure]; 4. grain-grain-hoed crop [+ manure]-grain-hay; 5. grain-grain-hoed crop [+ manure]-grain-grain-alfalfa-alfalfa-alfalfa-alfalfa-alfalfa; 6. grain-grain [+ manure]-grain-fallow; 7. grain-grain-grain-fallow. "Hay" refers to a mixture of grasses and clover. (Drawn from data reported by Shutt, F. T. 1925. Influence of grain growing on the nitrogen and organic matter content of the western prairie soils of Canada. Bulletin no. 44 – New Series. Department of Agriculture, Ottawa.)

tems: low forage yields, high capital costs of livestock production, unstable livestock markets, and others.[66,67] In the end, despite all the flaws of the fallow-grain system, it seems farmers had no better alternative. John Bracken, ever a pragmatist, said it this way: "If the fallow dissipates organic matter and nitrogen – and we regret that it does to a very serious degree – then we shall dissipate organic matter and nitrogen until we find a better way because we must have water in the soil and the fallow is the best way to get it there… . We recognize this serious objection to fallowing, but before dispensing with the fallow we want to be shown a better way."[68] Further, said the man who would one day be a prominent politician: "The individual finds a store of wealth in the soil and he does not hesitate to mine it. The State looks on more or less carelessly, realizing that it is being robbed, but offering no effective resistance because it knows none. And in many areas it has not yet set itself efficiently to the task of finding a more permanent system that is as profitable."[69]

The quest for a more diversified agriculture, then, was at least temporarily abandoned. (Even today, the near-extinction of wheat growing, prophesied by Rutherford, is not imminent.) And, not surprisingly, the network of innovative rotations that once spanned the country was quietly dismantled. Only a remnant of the sites from 1912 remain, at Lethbridge and Scott; and most of the rotations that remain, ironically, are the fallow/wheat systems originally established as 'controls' against which to test the superior, diversified systems.[70]

Predictions about Future Organic Matter Trends

Despite early fears of productivity collapse, scientists began to realize in the first decades of the 20th century that dissipation of organic matter might not continue indefinitely – even under cropping systems deemed "irrational". In 1922, Shutt re-sampled soils from Indian Head that, by then, had been cultivated for 38 years. He found that loss of organic matter from 1905 to 1922 was not as rapid as it had been from 1884 to 1905, and concluded that "There is undoubtedly a slowing down in this process of depletion, towards a point of constancy or equilibrium."[71] He had apparently anticipated the concept already in 1916, observing that "when we first till our rich soils in the Northwest, there is for the first five years or so a very heavy destruction of humus material. As we proceed we reach a minimum, or at least a limit, below which the destruction of the humus becomes slower and slower."[72]

Shutt even seemed to hint that there might be a limit to which organic matter, or at least fertility, could be increased. "The point is," he wrote in 1916, "the richer we have our soils by the addition of manure the larger will be the inevitable loss due to natural farm operations. There is a limit to which we can enrich our soils, and that limit is determined probably by climatic conditions, and partly probably by soil conditions."[73]

Thus, almost a century ago, scientists seem already to have grasped how organic matter responds to farming practices – that, after a management shift, organic matter first changes quickly, then eventually approaches a new equilibrium, reflecting the new management and local soil and climatic conditions. As articulated in a 1913 report[74], reviewing Shutt's work: "the Chemist concludes that the percentage of organic constituents – humus – is directly and indirectly a measure of the soil's fertility, and … this percentage is largely influenced by the treatment the soil received." This observation implies that organic matter response to a new management practice, for better or worse, is always of finite duration and magnitude, a truth that may be even more pertinent now than it was a century ago.

Other Research Areas

The preceding summary, of course, skates over numerous other questions that occupied prairie scientists a century ago. Many of these questions arose directly out of a search for a more "permanent" agriculture; many of them still vex us today. The following are a few examples.

Legumes and other Crops as Fallow Substitutes

If fallow hastens organic matter loss, can we grow legumes during the fallow period, thereby returning organic matter and nitrogen to the soil? This question was already posed in 1899 by MacKay: "The main object [of a new study] is to ascertain what advantage, if any, would arise from the use of leguminous plants for ploughing under … in place of the usual summer-fallow."[75] At about the same time, Bedford wrote that in Brandon "arrangements were made for a series of rotation plots, the principal object in view being the maintenance of the fertility of the soil, by ploughing under a leguminous crop every third year; instead of the usual summer-fallow.[76]

Evidently, results from these experiments were not promising. Alway and Trumbull, referring in 1910 to the Indian Head plots, reported: "Attempts to substitute for the bare fallow various leguminous crops, which have been plowed under, have decreased the yields of wheat. The lowered yields are evidently due to the drying out of the soil by the leguminous crop."[77] Similar views were expressed by Bracken a few years later: "The growing of green crops through a whole season in order to have a large growth to plow under … will not likely ever come into general use in the West, for the reason that the organic matter thus added to the soil is secured at the expense of … soil moisture which is itself generally the limiting factor in crop yields."[78]

For a time, corn grown in rows seemed a potential fallow-replacement. "Corn … may find a place as a partial substitute for the fallow and as a preparatory crop for wheat" [79], wrote Bracken in 1920. "When sown to corn in rows 36 inches apart or in hills 3 feet apart each way and kept free from weeds, the land next year generally produces almost as much as a fallow."[79] McKillican, too, proposed that "Corn is the best substitute for the summerfallow."[80] But within a few years, this idea too was discarded: "some cleaning crop other than corn will be required, as soon as summer fallow is either partially or wholly abandoned" concluded Champlin in 1923.[81]

And so, an economical, soil-preserving substitute for fallow eluded the early soil scientists (as, in some regions, it still does today).

Restorative Effects of Grass

If conversion of grassland to arable land results in precipitous loss of organic matter, does the reverse happen when land is re-seeded to grass? In 1907, Alway and Trumbull sampled a series of sites at Indian Head, all cultivated 25 years earlier, but some re-seeded to grass, sometimes with clover, after 7, 16, or 21 years (Table 3). Based on detailed analysis of organic C, total nitrogen, and "humus" (a fraction of organic matter), they found that all previously-cultivated sites had lost organic matter, but that "The longer the fields had been in grass the less has been the decline."[82]

Stubble Burning

Burning stubble for easier seeding was a common practice a hundred years ago. But researchers seem to have disagreed about its merits. MacKay wrote: "For wheat, the best preparation of this [stubble] land is to burn the stubble on the first warm, windy day in the spring, and either cultivate shallow before seeding or give one or two strokes of the harrow after seeding."[83] Millikan, his counterpart in Brandon, was not so sure: "Stubble burning is not advisable in Manitoba, *whether it be in Saskatchewan or not*. It is a waste of valuable vegetable matter that is very seldom justifiable" [84] (italics added). Bracken allowed that, under some conditions, "burning in the spring after the long stubble has been left to gather snow, is a practice that, for immediate profits, is conducive to large net returns"[85]. He worried, though, that burning of stubble wastes nitrogen and "dissipates 'organic matter', the constituent that helps to keep soils from blowing, the one that increases the water holding capacity of the soil and at the same time makes it easier to work"[86]. The practice may be "often immediately profitable, but it is permanently wasteful of soil fertility"[87]. And because there were no "long time records" of its impacts, he proposed that "the sooner we can find a substitute for burning stubble the better it will be for the land, as well as for the people who occupy the land after us"[88].

Reduced Tillage

The early writings, unexpectedly, reveal an interest in reduced tillage. In 1889, for example, MacKay observed: "Fall ploughing of stubble land has not given good results … . A much better way is to allow it to remain until spring, with as long stubble as possible to retain the snow."[89] Bedford at Brandon agreed, pointing out in 1895 that "it would appear from several years' experience here that fall-ploughing of clean stubble land for wheat is a waste of time" because it dried out the soil.[90]

Early researchers – a century ago – even seem to have contemplated a form of "direct seeding". "Drilling on the unploughed land keeps the stubble on the surface where it acts as a mulch"[90], wrote Bedford in 1895. This practice may have originated among early settlers; MacKay wrote in 1892 that "… thousands of acres are put in in the second, third, and even fourth year, without ploughing a furrow. The stubble is burned off, if possible, and the grain sown by drill and not touched again until cut."[91] A related practice was already investigated at Brandon in 1891[92] and at Indian Head in 1892[93]. MacKay, at Indian Head, reported a treatment in 1893 where "stubble land [was] sown by press drill without ploughing and not touched before or after using drill" [94] (Table 5). At Brandon, researchers compared various plowed systems with a treatment, referred to as "drilled on stubble", which "received no preparatory treatment, the seed being simply press drilled as deeply as possible with a Superior machine"[95]. In dry years, such as 1894 and 1895, the unploughed treatment yielded favorable returns (Table 5); as noted by Bedford: when rainfall was "somewhat below the average …, the unploughed soil retained moisture which was an advantage"[95]. Extensive tillage experiments at the University of Saskatchewan furnished similar results: Bracken reported that "in the 1912 crop uncultivated land produced as large yields as the most intensive tillage"[96]. Thus, "Seeding on the untilled stubble without previous or subsequent tillage" [97] was an established method[98], and " 'Stubbling in' the wheat in unplowed land" was common in parts of the prairies.[99] As late as 1924, a government report concluded that "It is often possible merely to drill the grain into the stubble without any previous preparation and harvest a crop quite equal of that which has been given a great deal more work."[100] We want to be cautious in reading these early writings – "ploughless" and "unploughed" do not always mean "untilled" – but it seems our forebears a hundred years ago were already studying reduced tillage, if not "direct seeding".[101]

If early results were promising, why did reduced tillage not come into general use until it was "discovered" almost a century later? First, " 'Stubbling in' the wheat in unplowed land" results "in the more rapid spread of weeds" and "should never be practised on grassy or weedy land or on land that does not have a natural mulch or seed bed in spring"[102]. Before the advent of reliable herbicides, lands cannot have remained free of weeds for long without intensive tillage, and, hence, "Seeding in untilled stubble land … should be discouraged."[103] Second, scientific thought seems to have been influenced, early in the 20th century, by a belief that "The great object of cultivation in the semi-arid region is to retain moisture. By breaking up the compact condition of the surface soil, the capillary rise of water to the surface is in large measure prevented."[104] This now-curious theory[105] was championed by notables such as H.W. "Dustmulch" Campbell, an American innovator who, in 1906 and 1907, was hired by the Alberta government to lecture on his methods in southern Alberta.[106–108] According to one contemporary, Campbell's "discovery" of the moisture-conserving technique was "worthy to rank him with Watt, Hudson, Eli Whitney and Edison"[109]. And, for a time, the theory held sway. Buller, a Manitoba botany professor, wrote that, in fallow, "surface tillage breaks the capillary tubes in the soil and so lessens evaporation"[110]. Rutter in 1911 contended that: "Harrowing is of great utility on the older cultivated parts of the prairies, for it produces a loose soil mulch for the conservation of moisture, and aids in the processes of sub-soil packing."[111] Bracken emphasized the moisture-conserving benefits of creating "a loose layer of soil two to four inches deep" soon after breaking the prairie

Table 5. Examples of data from early tillage experiments on the Canadian prairies. Where possible, treatment designations are those used by the original authors. Some care is necessary in interpreting these data because of uncertainty over authors' definitions of "not ploughed" or "unploughed" and scanty or ambiguous treatment descriptions. Not all data shown

Location	Year	Wheat yield (bushels/acre)[z]		
		Fall ploughing; stubble	*Seed gang-ploughed in; stubble*	*Not ploughed; stubble*
Indian Head[y]	1892	27.5	22.5	21.7
	1893	22.2	31.5	29.8
	1894	5.0	9.3	8.0
	Mean	18.2	21.1	19.8
			Spring ploughed	*Stubble burned off; wheat drilled in and harrowed*
Brandon[x]	1891		44.6	40.0
		Fall ploughed	*Spring ploughed*	*Drilled on stubble*
Brandon[w]	1894	17.2	23.0	26.3
	1895	18.7	24.2	34.7
	1896	No data	21.7	17.5
			With ploughing of stubble	*Without ploughing of stubble*
Brandon[v]	1895		24.7	33.3
		Cultivated or plowed	*No Cult. – grassy stubble*	*No Cult. – Clean stubble*
Saskatoon[u]		23.1	11.6	18.0

[z]Yields were reported in units of bushels + lbs per acre; values were converted to bu/acre, assuming a bushel weight of 60 lbs.
[y]MacKay, Angus. 1895. *In* Experimental Farms Reports for 1894. S.E. Dawson, Ottawa. p. 339. The three treatments are described as follows: "Each year a piece of stubble or root land has been ploughed in the fall and sown with Red Fife in the following spring; another piece has been gang-ploughed in spring at time of seeding; and another piece sown by drill without being worked before or after seeding." The "Seed gang-plowed in" was sown by broadcast; others with a drill. The 1893 data are also reported by MacKay in In Experimental Farms Reports for 1893. S.E. Dawson, Ottawa. p. 278. Here the unplowed treatment is described as "stubble land sown by press drill without plowing and not touched before or after using drill".
[x]Bedford, S.A. 1892. *In* Experimental Farms Reports for 1891. S.E. Dawson, Ottawa. p. 251. The full treatment descriptions were: "Ploughed in spring, harrowed with flat harrow and drilled; no weeds" and "Stubble burned off; wheat drilled in and harrowed with flat harrows; some weeds."
[w]This series is from: Bedford, S.A. 1895. *In* Experimental Farms Reports for 1894. S.E. Dawson, Ottawa. p. 290; Bedford, S.A. 1896. *In* Experimental Farms Reports for 1895. S.E. Dawson, Ottawa. p. 281; Bedford, S.A. 1897. *In* Experimental Farms Reports for 1896. S.E. Dawson, Ottawa. p. 324. The treatment designations vary among years. The "drilled on stubble" treatment is referred to as "sown on stubble without ploughing" for 1894 and "stubble unploughed" for 1896. Describing this treatment for 1894, Bedford writes: "The … plot was sown on summer-fallowed land in 1892, sown to wheat in 1893, and simply drilled in on the stubble [in spring of 1894]." For 1895 and 1896, he writes that the plot "received no preparatory treatment, the seed being simply press-drilled as deeply as possible with a 'Superior' machine." The fall-plough treatment in 1894 suffered wind damage.
[v]Bedford, S.A. 1896. *In* Experimental Farms Reports for 1895. S.E. Dawson, Ottawa. p. 291. Values are averages across two treatments: wheat after wheat and wheat after flax. Bedford also presents data for oats and barley, where ploughing had a more favorable effect on yield.
[u]Bracken, J. 1921. Dry Farming in Western Canada. The Grain Growers' Guide, Limited, Winnipeg. p. 164. The year(s) and duration of the study are uncertain, but the data may be from tillage studies in 1912 to 1914 referred to in Bracken, J. The tillage of stubble land. University of Saskatchewan, Saskatoon. Field Husbandry Circular No. 7. The value presented for "cultivated or plowed" is the mean of 6 treatments: "surface cult.", "burned and surface cult.", "deep fall plowing", "shallow spring plowing", "deep spring plowing", "shallow fall plowing". Yields for these treatments were similar, ranging from 22.4 to 23.6 bushels/acre.

sod[112], and, on stubble lands, he said: "Evaporation can be effectively lessened by creating and maintaining a soil mulch – a loose layer of dry soil on the surface of the field – through which moisture escapes very, very slowly."[113] Good farmers, Bracken said, "control 'evaporation' by tilling the land in such a way as to form a 'mulch' – a loose shallow layer of dry soil – on the surface of the field"[114]. But later, Bracken would admit that "The use of the unfortunate term, 'dust mulch' in so much of the Western Canadian and American agricultural literature, is responsible for at least a portion of the excessive drifting that has occurred in recent years. The 'dust' mulch has no place in the agriculture of any dry country where high winds prevail."[115] Kirk concurred: "There is no doubt but that excessive and improper cultivation of the summer fallow is responsible for a lot of unnecessary soil drifting. … Overemphasis of the dust mulch idea is largely responsible … . Extra cultivation simply with a view to preventing evaporation is not likely to pay for the work."[116]

We often think of reduced tillage methods as recent innovations, as triumphs of modern thought. But it seems the concept was already contemplated a century ago, only to be delayed by inadequate technology and a brief scientific detour.

The preceding are only a few examples of scientists long ago asking "modern" questions; others include: loss of nitrate via leaching[117], sampling strategies on a variable landscape[118], fractions of organic matter[119,120], effectiveness of commercial fertilizers[121–126], depletion of soil phosphorus over time[127,128], efficient manure management[129–132], impact of irrigation on accumulation of surface lime[133], soil microbes as a measure of soil productivity[134], and the link between parent material and soil carbon storage[135]. Many of these same questions still perplex and stimulate us today.

IMPLICATIONS OF YESTERDAY'S SCIENCE FOR TOMORROW'S

'New' Questions in the New Century

Science does not easily divulge ahead of time the questions that will engage its practitioners. Physicists at the end of the 19th century did not know enough to ask the questions that were soon to revolutionize science; indeed, Einstein's brilliance stemmed from a knack for pondering questions no one had foreseen. Only the exceptionally insightful (or arrogant) would dare predict publicly the questions that will puzzle and tantalize us decades hence.

But if the specific questions must elude us now, we can perhaps guess the underlying problem that will face soil scientists on the prairies. It may be the same problem that vexed and enticed our colleagues one hundred years ago – the problem of "permanence".

But now we have added new dimensions, so its scope is broader. One hundred years ago, the problem of permanence was simply: "How can farmers live and prosper on this land?" Soon was added the dimension of time: "How can farmers and all the generations that follow prosper on this land?". And more recently, we have expanded in space, moving beyond the boundaries of "this land": "How can farmers and all the generations that follow prosper on this land and not compromise, now or tomorrow, life beyond its fences?". So we wrestle now with questions about leaks into other environments: nutrients leaching into groundwater; greenhouse and other gases diffusing into the air; pest control agents seeping into water, air, and foods; new genes drifting into unintended genotypes. We ask these questions, already aware that conditions tomorrow may be different than they are now: the climate may be warmer, the CO_2 in air higher, and the demand for our products inverted.

And each new dimension has been superimposed over the previous one, not supplanting it. Thus "How can farmers live and prosper on this land?" is no less important now than it was a century ago. Bracken's words still apply – "The problem of the future lies in finding … the system that is at once the most profitable and the most permanent"[136] – but now "profitable" includes more than monetary returns, and "permanent" applies also to land, air, and water beyond the farm.

We, like our predecessors, are still trying to re-align the elements of our ecosystems – land, water, air, crops, livestock, people – into a "permanent agriculture". And it may be that, like those before us, we will still be trying to forge a "mixed farming" system, somehow melding crops and animals and people to avoid localized surpluses and deficiencies of nutrients, energy, products, and finances. In the end, are our core questions all that different than they were a century ago?

What Scientists of a Century Ago Can Teach Us

What can we learn from soil scientists of a century ago that may help steer our work in the next century? After listening to the thoughts of Shutt and Bracken and MacKay and Bedford, how can I now better probe future's riddles? Let me propose five things I want to have learned.

1. Look back more respectfully

A reading of the old papers instills new respect for the innovative and original thoughts expressed there; today's scientists do not have a monopoly on insight, the newest science is not always the best science. If a keen young student were to ask me which paper to read on organic matter in prairie soils – say, "Janzen. 1987. Soil organic matter characteristics…"[137] or, "Lawes and Gilbert. 1885"[138] – I would say, without reservation: read Lawes and Gilbert; the insights are deeper, the thoughts more original, the ideas fresher.

Focusing only on the present distorts our view. In recent decades, for example, we began fretting about the "Decaying Land", and the "threatened destruction of … agricultural productivity"[139]. And those worries did prompt some advances in our science; but had we taken the time to absorb the lessons learned over the past century, we might have answered the apparent threat with more insight – and more optimism.[140] How can we know if our farming methods have "permanence", how can we know if our lands are depleting or building, if we do not know what they have been?

A few years ago, Martin Alexander, the soil microbiologist, wrote: "Particularly intriguing in reviewing the past 75 years are the frequent papers that, based upon reading more recent literature, were long lost, but lo, the issues arose once again and even appear in the current literature. … The error of not looking back while thinking ahead was aptly depicted in a statement heard at a seminar, 'My research was confirmed by studies published 40 years ago'."[141]

The scientists of another era have taught me to spend more time in the library and to relinquish the attitude, as illogical as it is arrogant, that my insights, because they occurred to me recently, are more innovative than those of a century ago. I set about reading the old literature for perspective – and ended up acquiring fresh new knowledge.

2. Look Forward – Further

Second, I hope I have learned to do my work today with an eye to the distant future. When early scientists established their rotation studies, they knew not to expect final answers immediately. MacKay, writing about early experiments, said: "It is proposed to study these carefully over a long period of years, so that … we may secure information as to their effect on soil fertility." "It will require the evidence of many years …," he said, "before we can accept the results as being final…"[142]. (What would the network of rotation studies be worth today had we too looked further ahead?) I realize now that I have not been as far-sighted as Shutt, who insisted that when a soil sample was collected, "he wanted it so marked and recorded that another sample … could be obtained in the same spot ten or twenty years in the future"[143]

Far-sighted scientists look into the future, anticipate the questions that will be asked, and begin mulling them now. A blind preoccupation with questions now in the spotlight distracts from probing more fundamental questions that will emerge in time. The best science is not in solving today's puzzles, but in anticipating tomorrow's – and being ready for them. And the best way to prepare for them is to understand better how our ecosystems function.

3. Look Deeper

After reading the old literature, I realize with belated humility that my research is not always deeper, more penetrating than that conducted decades earlier.

In a 1921 paper read before the American Association for the Advancement of Science in Toronto[144], E.W. Allen said: "In the early stages of agricultural experimentation, … the work was naturally elementary, based largely on observations, comparative trials and simple experiments which did not attempt to determine underlying conditions or establish definite relationships. These types of work have given results which although largely empirical have been extremely useful. [But] they need to be replaced by more rigorous methods and by investigation which *goes to the heart of the problems*." [Italics added]. Said Allen: "It has been a somewhat prevalent mistake to assume that a complex agricultural problem could be solved in its practical aspects without a study of the principles and factors underlying it… . Unless there is a clear objective and an idea to guide in the acquiring of data, it may be a waste of time, an aimless, hopeless, dead effort."[144]

Shutt, in his 1916 Presidential Address to the Royal Society of Canada[145], also emphasized that research demanded the "enunciation of principles" rather than collection of "isolated facts". "The mere trying of this and that in an indiscriminate [manner], without any due regard to the laws of chemistry and biology that may be involved and without taking into account the numerous modifying factors and influencing conditions, without a study of the causes that may affect the results, while it may yield information of local importance, cannot add to the store of permanent knowledge of wide application.", he said. "It is of little value for the enunciation of principles; in a word, it cannot advance agricultural science." How did he define "principles"? "Let it be always borne in mind that the principles of agriculture, the outcome of research, are true the world over. If they do not hold good everywhere, they are not principles." And we might add: if they do not hold good over time, they are not principles.

Principles are not outdated, and sometimes become relevant in ways not foreseen. How could those who early studied organic matter have known that, generations later, their principles would apply to a method proposed to slow CO_2 buildup on a warming earth?

Today, we may become so distracted by our new capacity to collect data, that we forget the key to innovative science is – not the observations recorded – but the question posed at the outset. Without a question that cuts deeper than the one before, the data, regardless of their mass, can yield few new answers. Early scientists, fettered by slow data-gathering, may have been forced to spend more time contemplating new and deeper questions – questions that "go to the heart of the problem", questions about "principles". We are not always so lucky.

4. Look More Carefully, More Humbly

Scientists understand their chosen field better than any one; soil scientists on the prairies presumably know better than anyone the way their soils change in response to natural and human influences. But they will not always be right. Sometimes they may be led astray by weak theory – the "dust mulch" theory, for example, incited exuberant calls for expensive, intensive tillage that only depleted water and organic matter. And sometimes scientists may get the right answer, based on their own discipline, but overlook factors outside their expertise. Shutt and others, for example, were correct in espousing the dangers of fallow. But their solutions, which made such good Soil Science sense, had other weaknesses and, in the end, farmers often *needed* summer fallow to survive.

If I am prone to error, then, do I avoid conclusions until I am certain? Not necessarily. But I want to be cautious about parading favorite theories as truth. Seager Wheeler, champion wheat grower, evidently admired "Professor Bracken" because he had "the unique reputation of being very conservative in his statements and in the advice which he gives… . While theory is all right in its way, there must be proof of it in actual field practice before he will make a definite statement as to any course to be pursued."[146] And I want to be more wary about vociferously promoting findings not yet mature. C.E. Saunders wrote: "We must encourage silence rather than loquacity … . The public must learn to wait."[147] Often the public is not content to wait; but it deserves, at least, to be told of lingering uncertainty when I present my answers, however elegant and refined they may seem to me.

5. Look for Beauty

Emerging from the old literature is a sense of wonder, a sense of awe in the object of study. A century ago, soil science was still young, and the allure of soils' mysteries had not yet been dulled by over-analysis. Sir E.J. Russell, at the 1924 meeting of the British Association for the Advancement of Science in Toronto, said: "How many farmers know anything about the remarkable structure of the soil they till, of its fascinating history, of the teeming population of living organisms that dwell in its dark recesses; of the wonderful wheel of life in which the plant takes up simple substances and in some mysterious way fashions them into foods for men and animals and packs them with energy drawn from sunlight – energy which enables us to move and work, to drive engines, motor-cars, and all the other complex agencies of modern civilization? No one knows much about these things; but if we knew more, and could tell it as it deserves to be told, we should have a story that would make the wildest romance of human imagination seem dull by comparison." He added: "Agricultural science must be judged not only by its material achievements, but also by its success in revealing … something of the wonder and the mystery of the great open spaces in which [the farmer] dwells." [148]

This sense of awe, more than any other factor, will ensure, I think, that Soil Science on the prairies stays vibrant, fresh, and new in this new century. Though I may never admit it to my superiors (or in a grant proposal), innovative science is driven less by the desire to furnish a practical solution, than by a quest for beauty and harmony. As pointed out about a century ago by Henri Poincaré, a mathematician[149]:

> The scientist does not study nature because it is useful;
> he studies it because he delights in it,
> and he delights in it because it is beautiful.

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NOTES AND SOURCES

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2. Glass, Bentley. 1971. Science: Endless horizons or golden age? Science **171**: 23–29.

3. Horgan, John. 1997. The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age. Broadway Books, New York. p. 84.

4. See, for example: Maddox, John. 1998. What Remains to Be Discovered: Mapping the Secrets of the Universe, the Origins of Life, and the Future of the Human Race. Martin Kessler Books, New York. 434 pp.

5. I use "scientist" here in the broad sense, denoting a spirit of inquiry, rather than position title or academic achievement. Indeed, scientific advances on the prairies often arose from the insights and ingenuity of people unencumbered by academic qualifications.

6. W. M. Saunders. 1894. Experimental Farms Reports for 1893, S. E. Dawson, Ottawa. p. 6.

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8. Lawes, J. B. and Gilbert, J. H. 1885. On some points in the composition of soils; with results illustrating the sources of the fertility of Manitoba prairie soils. Journal of the Chemical Society **47**: 380–422.

9. Shutt, F. T. 1890. Experimental Farms Reports for 1889, Brown Chamberlain, Queen's Printer and Controller of Stationary, Ottawa. p. 43.

10. Shutt, F. T. 1891. Experimental Farms Reports for 1890, Brown Chamberlain, Queen's Printer and Controller of Stationary, Ottawa. p. 109.

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12. cited by Ellis, J. H. and Shafer, W. 1928. The nitrogen content of Red River Valley soils. Scientific Agriculture **9**: 231–248. See similar quote attributed to George Dawson in Shutt, F. T. 1898. Experimental Farms Reports for 1897, S. E. Dawson, Ottawa., p. 165. *and* Rutter, W. P. 1911. Wheat-growing in Canada, the United States, and the Argentine. Adam and Charles Black, London. p. 44. [These quotes refer to the very rich soils of the Red River Valley.]

13. Shutt, F. T. 1910. Western Prairie Soils: Their Nature and Composition. Department of Agriculture, Central Experimental Farm, Ottawa ON. Bulletin No. 6, Second Series. pp. 10-11.

14. Lawes, J. B. and Gilbert, J. H. 1885. On some points in the composition of soils; with results illustrating the sources of the fertility of Manitoba prairie soils. Journal of the Chemical Society **47**: 380–422.

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16. F. T. Shutt. 1906. Experimental Farms Reports for 1905, S. E. Dawson, Ottawa., p. 128–129. Similar values are presented by Shutt, F. T. 1910. Western Prairie Soils: Their Nature and Composition. Department of Agriculture, Central Experimental Farm, Ottawa ON. Bulletin No. 6, Second Series.

17. Alway, F. J. and Trumbull, R. S. 1910. A contribution to our knowledge of the nitrogen problem under dry farming. Journal of Industrial and Engineering Chemistry **2**: 135–138.

18. Hansen, R. 1921, The soil. pp. 45–77 *In* Bracken, John. Dry Farming in Western Canada. The Grain Grower's Guide, Limited. Winnipeg, Canada. 386 pp. (p. 55)

19. see, for example:
McGill, W. B., Dormaar, J. F. and Reinl-Dwyer, E. 1988. New perspectives on soil organic matter quality, quantity, and dynamics on the Canadian prairies. Pages 30–48 *in* Proceedings of the 34th annual CSSS/AIC meeting., University of Calgary.
Anderson, D. W. 1995. Decomposition of organic matter and carbon emissions from soils. Pages 165–175 *in* R. Lal, E. Levine, and B. A. Stewart, eds. Soils and Global Change. Lewis Publishers, Boca Raton, FL.
Janzen, H. H., Campbell, C. A., Izaurralde, R. C., Ellert, B. H., Juma, N., McGill, W. B. and Zentner, R. P. 1998. Management effects on soil C storage on the Canadian prairies. Soil Till. Res. **47**: 181–195.

20. Bailey, L. H. (Ed.). 1907. Cyclopedia of American Agriculture: A popular survey of agricultural conditions, practices and ideals in the United States and Canada. The MacMillan Company. New York. pp. 372–373. For example, the following is an excerpt translated from Vergil's verse:

But on the alternate seasons hold thine arm
And the field newly gathered assail thou not.
Suffer it rather for so long to lie
Fallow and thirsty, under the parching sky.

21. Bracken, J. 1921. Dry Farming in Western Canada. The Grain Growers' Guide, Limited, Winnipeg. 386 pp. (p. 6–7).

22. McKay (*sic*), Angus. 1913. Origin of summer fallows. Farm and Ranch Review (January 6, 1913): 6–7.

23. For a detailed history of fallow on the prairies, see also: Oliver, E. H. 1935. The Beginnings of Agriculture in Saskatchewan. Transactions of the Royal Society of Canada **24**: 1–35.

24. MacKay, Angus. 1911. Report of the Agriculturist, in Experimental Farms Reports for 1910, C.H. Parmlee, Ottawa. p. 416 (quoting 1889 report)

25. MacKay, Angus. 1895. Indian Head, Experimental Farms Reports for 1894, p. 333.

26. MacKay, Angus. 1902. Experimental Farms Reports for 1901. S.E. Dawson, Ottawa. p. 505 (also appears in other reports).

27. MacKay, Angus. 1910. Experimental Farms Reports for 1909. C. H. Parmlee, Ottawa. p. 333. [MacKay insisted, however, that summer fallow was important "to store up moisture against a possible dry season, to restrain the weeds from over-running the land and… to prepare at least a portion of the land to be cropped, in the year previous to seeding".]

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30. Shutt, F. T. 1910. Western Prairie Soils: Their Nature and Composition. Department of Agriculture, Central Experimental Farm, Ottawa ON. Bulletin #6 Second Series. p. 12.
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32. Bracken, J. 1918. Summary of Results of Investigations of Experiment Plots. University of Saskatchewan. p. 12.
33. Murray, James.1911. Experimental Farms Reports for 1911. C. H. Parmlee, Ottawa. p. 367.
34. Shutt, F. T. 1916. Soil fertility: Its economic maintenance and increase. Department of Agriculture, Bulletin No. 40. p. 3.
35. Shutt, F. T. 1910. Western Prairie Soils: Their Nature and Composition. Department of Agriculture, Central Experimental Farm, Ottawa ON. Bulletin No. 6, Second Series. p. 21 (excerpt from Footnote).
36. Anonymous. 1912. Dominion Experimental Farms: A guide to the experimental farms and stations. Government Printing Bureau. Ottawa. 1912. 162 pp. (p. 95)
37. Report of the Royal Commission of Inquiry into Farming Conditions. Province of Saskatchewan, Regina. 1921. pp. 35–36.
38. Wheeler, S. 1919. Seager Wheeler's Book on Profitable Grain Growing. The Grain Growers' Guide, Limited, Winnipeg. pp. 117–118.
39. Bracken, J. 1921. The management of drifting soils. University of Saskatchewan, Saskatoon. Field Husbandry Circular No. 28. 7pp. (excerpt from "Dry Farming in Western Canada", The Grain Growers' Guide, Limited, Winnipeg. 1921; publication date of Circular is estimated).
40. In recent years, we have used the term "sustainability" to refer to the concept our predecessors called 'permanence'. Though we have given it a new name, the concept is certainly not new (and our name for it may not be better than theirs).
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42. *Ibid.* p. 209.
43. Shutt, F. T. 1910. Western Prairie Soils: Their Nature and Composition. Department of Agriculture, Central Experimental Farm, Ottawa ON. Bulletin #6, Second Series. p. 25.
44. Murray, J. 1911. Experimental Farms Reports for 1911. C.H. Parmlee, Ottawa. p. 368.
45. Bedford, S. A. 1894. Experimental Farms Reports for 1893. S. E. Dawson, Ottawa. p. 243.
46. Grisdale, J. H. 1912. Experimental Farms Reports for 1912. C. H. Parmlee, Ottawa. pp. 26–27.
47. Bracken, J. 1918. Summary of Results of Investigations of Experiment Plots. University of Saskatchewan. p. 13.
48. Ellis, J. H. 1970. The Ministry of Agriculture in Manitoba: 1870 - 1970. Manitoba Department of Agriculture, Winnipeg. p. 233.
49. Ellis, J. H. 1971. The birth of agronomic research at the Manitoba Agricultural College. Winnipeg, Manitoba. 181 pp. (p. 68).
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52. Bracken, J. 1920. Crop Production in Western Canada. The Grain Growers' Guide, Limited, Winnipeg. 423 pp. (p. 237–238).
53. Report of the Royal Commission of Inquiry into Farming Conditions. Province of Saskatchewan, Regina. 1921. p. 55.
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55. Though Shutt and other early scientists often focused on total N content, they understood well the close link between nitrogen and organic matter concentration. For example, in 1898, Shutt wrote: "Analysis has shown that the amounts of humus and nitrogen are, generally speaking, closely related, and that the former is a measure of the latter". (F. T. Shutt. 1898. Barn-yard manure. Bulletin No. 31. p. 10.) Later he would write: "The organic content as determined by 'loss on ignition' follows very closely the nitrogen, so that the ratio, nitrogen to organic matter, is more or less constant." (Shutt, F. T. 1925. The influence of grain growing on the nitrogen and organic matter content of the Western Prairie soils of Canada. Journal of Agricultural Science, Cambridge **15**(2): 162–177.)
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57. Anonymous. 1912. Page 104 *In* Dominion Experimental Farms: A guide to the experimental farms and stations. Government Printing Bureau. Ottawa. 1912. 162 pp.
58. Hansen, R. 1921. The soil. Pages 37–77 *in* Bracken, John. Dry Farming in Western Canada. The Grain Grower's Guide, Limited. Winnipeg, Canada. 386 pp. (p. 56).
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61. McKillican, W. C. 1921. Dry farming in Western Manitoba. Pages 336–342 *in* Bracken, J. 1921. Dry Farming in Western Canada. The Grain Growers' Guide, Limited, Winnipeg. 386 pp. (p. 336).
62. Ellis, J. H. 1970. The Ministry of Agriculture in Manitoba: 1870–1970. Manitoba Department of Agriculture, Winnipeg. p. 611.
63. Kirk, L. E. 1922. The Summerfallow. University of Saskatchewan; College of Agriculture; Department of Field Husbandry, Saskatoon. p. 3.
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67. Murray, S. N. 1967. The Valley Comes Of Age: A History of Agriculture in the Valley of the Red River of the North, 1812–1920. North Dakota Institute for Regional Studies, Fargo. p. 160.
68. Bracken, J. 1915. The Summerfallow. Government of the Province of Saskatchewan, Department of Agriculture. p. 5 (publication date is estimated; a similar quote appears in Bracken, J. 1921. Dry Farming in Western Canada. The Grain Growers' Guide, Limited, Winnipeg. 386 pp.. [p. 174–175])
69. Bracken, J. 1920. Crop Production in Western Canada. The Grain Growers' Guide, Limited, Winnipeg. 423 pp. (p. 237).

70. Janzen, H. H. 2001. Long-term agroecosystem sites in Canada: what have they taught us, and what might they yet teach us? *In* Proceedings of the Soil-Carbon-Food Symposium, University of Alberta, July 1999 (in press).
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72. Shutt, F. T. 1916. Soil fertility: Its economic maintenance and increase. Department of Agriculture. Bulletin No. 27, Second Series, p. 5.
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74. Spencer, J. B. 1913. Dominion Experimental Farms: A Review of the Work of the Experimental Farms. Government Printing Bureau, Ottawa. p. 68.
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90. Bedford, S. A. 1896. Experimental Farms Reports for 1895. S.E. Dawson, Ottawa. p. 282.
91. MacKay, Angus. 1893. Experimental Farms Reports for 1892. S.E. Dawson, Ottawa. p. 227. [The full comment seems intended as a reproach.]
92. Bedford, S. A. 1892. Experimental Farms Reports for 1891. S. E. Dawson, Ottawa. p. 251.
93. MacKay, Angus. 1893. Experimental Farms Reports for 1892. S. E. Dawson, Ottawa. p. 232.
94. MacKay, Angus. 1894. Experimental Farms Reports for 1893. S.E. Dawson, Ottawa. p. 278.
95. Bedford, S. A. 1897. Experimental Farms Reports for 1896. S. E. Dawson, Ottawa. p. 324. See also, S. A. Bedford. 1896. Experimental Farms Reports for 1895. S. E. Dawson, Ottawa. p. 281. ["Superior", evidently, is the brand name of the seed drill.]
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97. Bracken, J. 1921. Dry Farming in Western Canada. The Grain Growers' Guide, Limited, Winnipeg. 386 pp. (p. 153).
98. Buller, A. H. R. 1919. Essays on Wheat. The MacMillan Company, New York. p. 43.
99. Bracken, J. 1920. Crop Production in Western Canada. The Grain Growers' Guide, Limited, Winnipeg. 423 pp. (p. 111).
100. Anonymous. 1924. The Organization Achievements and Present Work of the Experimental Farms. Government Printing Bureau, Ottawa. p. 38.
101. Early scientists even proposed that tillage depleted organic matter (though they may not have understood the mechanism). In 1906, Shutt wrote: "plowing, harrowing and indeed all mechanical operations that tend to open up the soil, must result in the oxidation and, consequently, the loss of a portion of the humus (semi-decayed vegetable matter) and its concomitant nitrogen" (Shutt, F. T. 1907. Experimental Farms Reports for 1906. S. E. Dawson, Ottawa. p. 155.)
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150. In selecting and weaving together quotes from the old writings, I have undoubtedly sometimes introduced my own biases, and may, regrettably, have misconstrued or diluted the thoughts of our forerunners. I invite readers to go to the original sources and find there the full force of our forebears' thoughts, undiminished and undistorted by my selective culling.