Annoted Bibliography on Soil Erosion by Wind

Applicable to Southern Alberta Agriculture

Prepared for

Region II Soil Management Committee

By

Ken K. Krogman

March 1983

Soils Branch
Alberta

Addendum

The following reference was not originally included however it provides a good overview of the erosion problem. Chapter 1 describes wind erosion in perspective. Chapter 7 comprises an extensive review of wind erosion research, and a thorough but understandable discussion of the what, where, when, how and why of wind erosion.

Wilson, S.J. and R.U. Cooke. 1980. Wind erosion. P. 217-251. In Kirby, M.J. and R.P.C. Morgan ed. Soil erosion. John Wiley and Sons. Toronto.

Table of Contents

Abstract

The publications listed here were selected from holdings of the Agriculture Canada Research Station Library, Lethbridge and from the private holdings of some of the staff of Alberta Agriculture and Canada Agriculture at the Agriculture Center, Lethbridge. The Bibliography of Dryland Agriculture, 3rd ed., Oregon State University, Corvallis, Oregon, and the Biological and Agricultural Index, H.W. Willson Company, New York were consulted.

The publication by Moats, bibliographic file number 011, is of particular inte`rest. It is an annotated bibliography of wind erosion and sand dune control covering 1803 to 1939 and has 443 listings indexed according to key words and authors. The present listing is somewhat restricted in geographical area and so is not an updating of the publication by Moats. But the Moats bibliography would be a useful key for study of the wind erosion literature for earlier times.

The Bibliographic File is listed chronologically. The Subject Index can be used to find the articles that mention or deal with certain specific topics. Some of the articles discuss few topics; others, many. Articles that are very comprehensive and deal with causes, damages, precautions and controls of wind erosion are indexed under "General Discussion".

The summary notes that accompany each citation are mostly contractions of abstracts or summary sections of the articles. Thus, all of the information given in the articles will not necessarily be carried into the annotations given here. Every effort was made to note the essential information while retaining brevity. Where further information is required, the original papers must be consulted. Most of them should be readily attainable.

Review

"Below the thin layer composing that delicate organism known as soil is a planet as lifeless as the moon". This quotation (Jacks and Whyte in Vanishing Lands, a World Survey of Soil Erosion, 1973) emphasizes the importance of soil to Man.

The National Association of Conservation Districts, U.S.A (117) [1] stated, "There is a limit to the extent which applied science can temporarily force up soil productivity but there is no limit except zero to the extent which erosion permanently reduces it". Note that increases are termed <u>temporary</u> and decreases due to erosion are termed <u>permanent</u>.

Soil is the product of geologic parent material acted upon by climate and vegetation over time, but the rate of soil development is slow. It is too slow to be of practical consideration in replacing soil lost to avoidable erosion. Although the concept of "allowable" or "tolerable" amounts of erosion ("T values") that are equal to the rate of soil formation have been proposed, the idea is much debated. Besides, the estimated T values, averaging about 7 tons of soil per acre per year are extremely small. It is unlikely that soil erosion can be controlled within such precise limits.

Estimates of the costs of erosion are more meaningful. Crop yields may be reduced by about 3.4 bushels per acre per year per inch of topsoil lost (109). Fertility loss from eroding soils has been estimated to be 37 to 74 dollars per acre per year. Another study at Lethbridge (112) indicated that the difference in net returns from undisturbed and eroded soils (20 cm of topsoil removed) average 100 dollars per acre per year at 1980 prices.

The cost of erosion extends beyond the farm to society in general. The literature refers to the cost of relocation and rehabilitation of people from areas of severe soil drifting. Soil drifting creates the annoyance of air-born dust, dangers to traffic, and blockage of roads and structures such as drainage and irrigation ditches.

The U.S. Conservation Service (054) warns that "all who till or graze the Great Plains must adopt good land use and soil and water conservation practices and plan for recurrent droughts to have a permanent and profitable agriculture. The alternative is bigger and worse dust bowls with each succeeding drought. And there will be more droughts because these are a normal feature of the climate of the region". The Canadian prairies are part of the Great Plains of North America and so are subject to the above warning.

An early reference to soil erosion by wind in the three prairie provinces was made in 1920 as a topic of discussion of a meeting of the Western Canadian Society of Agronomy, an organization no longer in existence. The area of serious soil drifting in Southern Alberta was described at that meeting by Fairfield (002) as a triangular area with its apex at Pincher Creek and extending north-east about 100 miles. Later reports, for example those by Toogood (075,097) showed that the area of concern extends well beyond the area delineated by Fairfield and includes much land in central Alberta as well.

Danger of wind erosion is in direct proportion to duration and frequency of winds strong enough to cause drifting. The Alberta Farm Guide, 1976, indicates that winds equal to or exceeding 32 m.p.h. annually occur for more than 500 hours in the Lethbridge area, with a decline in number of hours northward so that between 50 and 100 hours of 32 m.p.h. or greater winds occur in the area east of Calgary. While this may indicate a greater soil drifting hazard in the Lethbridge area, winds of sufficient velocity and duration to cause a soil drifting problem certainly occur in the area east of Calgary.

Soil drifting, particularly during the windy seasons of fall, winter and spring was recognized as a problem in Southern Alberta at least as early as 1920 (002). Palmer (064) indicated that wind erosion was prevalent in the chinook belt in the early 'teens. It is well known that soil drifting continued to be a problem and became very serious in the dry years of the 1930s. In 1936, Palmer (008) wrote, "---- soil drifting is

[1] Numbers in brackets are bibliographic file listings.

undoubtedly one of the greatest difficulties that the grain farmer of the prairie has to meet. Sands and clays are most susceptible. Most drifting occurs on bare fallow. Plowless fallow is necessary, trash must be conserved and strip cropping is recommended. Some areas should be removed from cultivation". In 1968 Palmer (064) indicated that soil drifting continued to be a menace due to neglect to apply the known remedies. He said, "With us in the 1930s it was a matter of finding out what to do. Now it requires only doing that which has been tried and found to be good. There is no longer any excuse for permitting the soil to blow away. Any soil drifting is a result of carelessness, misjudgement or poor planning and is a mark of some form of poor husbandry".

That soil drifting continues to occur is indicated by Anderson's statement (084) in 1975, "Westerly winds swept across Southern Alberta and reached speeds of 55 m.p.h. at Lethbridge on Saturday, October 4. In several farm fields tons of topsoil billowed skyward in destructive protest against lack of wind protection. Many fallow fields, cropped in narrow strips, snuggled contentedly under a protective blanket of trash cover, of good clod structure or (in some cases) of a well-developed cover crop". In 1982 Davidson (131) stated that, although not so evident as in the '30s, soil erosion is still a serious problem. Summerfallowing, destruction of grassed waterways and fall incorporation of herbidices have been largely responsible.

For wind erosion to begin, the exposed soil must be in a susceptible condition and wind velocity must be sufficient to initiate soil movement. The threshold wind velocity (wind velocity at which soil movement begins) depends upon the grain size of the soil and the present. Chepil (012) estimated threshold wind velocity for highly erodible soils to be 8 to 9 m.p.h. Depending on the history and condition of the field, threshold velocity normally ranges between 13 and 30 m.p.h., measured one foot above the soil surface. Disposition of the soil to wind erosion involves soil texture, structure and protection. Aggregates between 0.1 and 0.5 mm. diameter are most susceptible to erosion. Clay and sandy soil are more likely to erode than medium textured soils. Vegetative cover or crop residue protects against wind erosion by sharply reducing wind velocity at the soil surface and by preventing drifting to start. A cloddy surface will also give protection. However, freeze-dry action on exposed bare soil may break down the clod structure, destroy aggregation, and render the soil highly erosive.

Basic research during the 1940s and 1950s by Chepil, Bisal and others revealed many of the physical principles underlying wind erosion. Most movement of drifting soil is by a process called saltation. Erodible particles are dislodged, carried a short distance and bombard other particles which are in turn dislodged. Thus, up to a point, the intensity of drifting increases with distance. The very fine particles become suspended, creating dust clouds, and the coarser, less fertile particles accumulate in drifts. Since erosion tends to be cumulative with distance, erodibility of a field is proportional to the width of the field in the direction of the wind.

Preventive measures are based on eliminating the causal factors. Most of the preventive measures were known and talked about when wind erosion was first recognized as a serious problem on prairie farms. The preventive measures include maintaining a non-erosive condition of the soil itself by keeping a cloddy structure at the soil surface. This is done by using cultural machines that bring clods to the surface and do not destroy them. Spring tooth dultivators or chisel cultivators are examples of such machines. Plowing will also leave a cloddy surface, but plowing defeats the other protective measure - maintenance of stubble and trash on the soil surface. Disc harrows, and particularly drag harrows should not be used because these machines pulverize the soil.

Prevention of wind erosion is also achieved through protection from the wind. Trash cover on uncropped land consisting of stubble and straw on the surface protects the soil. During the off-crop season, only sufficient cultivations should be done to control weeds, using machines that do not bury all the stubble and straw. Wide sweep or blade cultivators, duck-foot cultivators or rod weeders are best for this. The one-way disc and flexible disc harrow are less effective in trash conservation, but better than the plow. Speed and depth of operation of disc implements may be critical. Maximum conservation is achieved when speed is moderate, depth of cut is shallow and the pan angle is narrow.

Living or dead plant material may also provide wind protection. Included here are cover crops (usually an annual crop such as oats, planted in late summer) to provide protection during the critical fall, winter and spring seasons. Also included here are field shelter belts and barrier strips. The barrier strips consist of one or two rows of a tall-growing grass or an annual plant such as flax, seeded every 50 to 75 feet across the direction of the prevailing wind. Field shelterbelts and barrier strips reduce wind velocity for a distance about 20 times their height on the leeward side. In addition to providing wind protection, shelterbelts and barrier strips trap snow which helps to guard against the alternate freeze - thaw destruction of soil aggregates. Additional soil moisture from the trapped snow may also increase crop yields, enable more nearly continuous cropping, and result in heavier crops that can provide more stubble and straw for protective trash cover.

The practice of strip cropping began in Southern Alberta in the late 'teens and by 1930 much cultivated land in Southern Alberta was strip cropped. In this system, strips of crop alternate with strips of fallow across the direction of the prevailing wind. The strips must be narrow enough to prevent serious soil drifting from developing within the width of the strip. Narrower strips (80 to 160 ft. wide) are required on the more erodible sandy or clay soils. Wider strips (160 to 320 ft. wide) may be used on the less erodible medium-textured soils. A combination of strip cropping and trash conservation with blade or cultivator implements on summerfallow will almost certainly provide complete protection against wind erosion. The only exception would be highly erodible soils that should not be used for annual crops and should be left permanently seeded to grass.

Dealing with the wind erosion problem is somewhat different on irrigated land than on dryland. On irrigated land, summerfallow should be unnecessary. All irrigated land should support a crop during the growing season. However some crops may not provide much wind protection in the spring, and erosion prevention will depend on a roughened, lumpy soil surface. Aftermath of irrigated crops is often fed to livestock in the field and trampling may render fields very erodible. Such fields need to be roughened with a cultivator or chisel cultivator. Where danger of erosion in seedling row crops is severe, strips of cereal plantings or barriers have been suggested as preventive measures.

The primary and most important methods to combat wind erosion are preventive. Where prevention has not been provided or was inadequate, and soil drifting has started, emergency measures must be used to stop further damage. Erosion usually begins at "focal" points, or spots where the soil is most easily eroded. Such focal points should be detected early when the drifting can usually be stopped by spreading straw or manure. A light discing may be required to anchor the straw. Where large areas are drifting, cultivation with a chisel cultivator, set to bring lumps to the surface and produce ridges, can be used, travelling across the direction of the wind and beginning on the windward side of the field. Where the soil is loose and dry to ordinary cultivation depth, listers may have to be used. For this purpose a cultivator with all but one of every three shovels removed or a one way with all but one of every four pans removed, can be used and operated deep enough to produce ridges and bring clods to the surface. If a second listing is necessary, the furrows should be drawn between the previous furrows.

The causes of wind erosion, damage created, and principles of prevention and control were known and talked about more than 60 years ago. The physical processes involved were extensively researched between 1940 and 1960 and are mostly well understood.

In the past 20 or 30 years the technology of implementing known preventive and corrective measures has greatly improved. This includes the development of large farm machines capable of performing field operations quickly and effectively, chemical control of weeds and new, more drought-tolerant varieties of grain, particularly wheat and barley.

Large, powerful machinery allows field work to be done when weeds are most easily killed. Higher-yielding varieties of crops may produce more straw and stubble, giving more protective trash cover. Herbicides can be used to control weeds without soil disturbance and destroying or burying trash cover.

Herbicides make possible grain farming with only enough cultivation to allow planting the seed. This "minimum-till" or "no-till" method of soil management should almost completely eliminate risk of wind erosion. However, all aspects of the "minimum-till", "no-till" or "zero-till" concept has not been fully researched and developed. It is not yet certain if replacement of cultivation completely with chemical weed control is economically sound and entirely desirable. Special seed drills that perform satisfactorily in heavy trash and in consolidated soil are needed, and sprayers are a major part of the farm equipment. Savings in fuel costs may be offset by the cost of expensive herbicides. Timeliness of operations is more critical than with conventional cultural methods. Such questions as fertilizer placement under no-till management remain to be solved. Comparative energy costs may have a bearing on the desirability of minimum-till and chemical weed control over conventional soil management.

Modern farming methods have been conducive to soil conservation and prevention of wind erosion. Combine harvesting instead of stook-threshing returns all of the straw to the field. Large tractors pulling wide sweep cultivators make field operations more timely with respect to weed growth and soil moisture conditions than small tractors or horses pulling small cultivators or disc harrows.

On the other hand, big equipment has led to big fields and wide field strips. When dry years with windy weather come again, as they surely will, some of the large fields and wide field strips may begin to blow. We should be on guard.

BIBLIOGRAPHIC FILE

001 Hansen, R. 1920. Soil drifting in Saskatchewan. Proc. Meeting of the Western Can. Soc. Agron. 1: 49-59.
The southwestern part suffers worst, estimated damage is more than 5 percent, and is on the increase. The damage is to people as well as to land and proposals to relocate farmers are being made. Organic matter of the soil should be increased by growing grass. Cover crops should be used. The dust mulch idea was unfortunate. The need is to co-ordinate and put into practice our present knowledge - boiled down to two words, "systematic rotations."

002 Fairfield, W.H. 1920. Soil drifting in Alberta. Proc. Meeting of the Western Can. Soc. Agron. Edmonton. 1: 35-37.
A triangular area beginning at Pincher Creek and extending east for about 100 miles is an area of severe soil drifting. There was not much problem when the land was new but some lands should not have been broken. To control - plow only when the soil is moist, do not disc, maintain clodiness, strip crop and use winter rye.

003 Ellis, J.H. 1920. Soil drifting in Manitoba. Proc. Meeting of the Western Can. Soc. Agron. Edmonton. 1: 38-48.
The most serious area of wind erosion is in the south-western part of the province. The causes are insufficient root fibre, lack of cohesion between soil particles, high winds and predisposing climatic factors. Damages include erosion, harm to young crops, deposition of drift soil on fields not eroded, abrasion action by wind-born sand and soil loss. Relief measures include spreading straw or manure, plowing furrows or "roughing up" with a cultivator. Prevention measures include fallowing in strips, using cover and pasture crops, cultivating only with a cultivator and topdressing with manure.

004 Fairfield, W.H. 1920. Soil drifting in Southern Alberta. Conservation of soil fertility and soil fibre. Report of a Conference held at Winnipeg. Kings Printer, Ottawa pp 75-78.
Large amounts of root fibre prevented the soil from blowing when it was first broken but continuous cultivation has destroyed the fibre and the soils drift. Control includes (1) Irrigation, (2) Community effort, (3) Develop our own methods, (4) Diversify the farm operations (5) Use cover crops, (6) Recognize the problem.

005 Wyatt, F.A., J.M. Smith, R. Newton and C.C. Gillies. 1932. Soil drifting and its control. Univ. Alta. Coll. Agr. Circ. 13.
A symposium of four radio talks: Soil types and management in relation to soil drifting by F.A. Wyatt, The influence of machinery on soil drifting by J. Macgregor Smith, Cropping systems and shelter belts by C.C. Gillies.

006 Hopkins, E.S. 1935. Soil drifting in Canada. Trans. 3rd Int. Congr. Soil Sci. (Oxford) 1: 403-405.
Drought and high wind velocity are the main causes of drifting. Alternate strips of grain and summerfallow, and cover crops are the recommended control measures.

007 Moss, H.C. 1935. Some field and laboratory studies of soil drifting in Saskatchewan. Sci. Agric. 15: 665-679.
The drifted material from heavy soils is practically identical to undrifted soil. Drift from sandy soils is lighter in texture but low in fertility. From medium-textured soils, drift is also lighter than the original but is more fertile than drift from sandy soils. Drifting destroys fertility by removing the fertile fraction of the soil or by depositing material of inferior fertility on otherwise fertile fields.

008 Palmer, A.E. 1936. The soil drifting problem in the prairie provinces. Sc. Agr. 16: 264-265.
"----soil drifting is undoubtedly one of the greatest difficulties that the grain farmer of the prairie has to meet". Sand and clays are most susceptible. Most drifting occurs on bare fallow. Plowless fallow is necessary, trash must be conserved and strip cropping is recommended. Some areas should be removed from cultivation."

009 Hopkins, E.S., A.E. Palmer and W.S. Chepil. 1937. Soil drifting control in the prairie provinces. Canada Department of Agriculture. Farmers Bulletin 32. 51 pp.
Strip farming, surface cultivation and cover crops are found to be successful methods to control soil drifting.

010 Chepil, W.S. and R.A. Milne. 1939. Comparative study of soil drifting in the field and in a wind tunnel. Sci. Agr. 19: 249-257.
In both the portable wind tunnel and in the open field most of the blown material is carried in saltation. The saltation movement in the wind tunnel and the field was similar, establishing the usefulness of the tunnel in wind erosion studies.

011 Moats, R.W. 1940. Wind erosion and sand dune control; a selected list of references. U.S.D.A. Soil Conserv. bibliography no. 1 56 pp.
A bibliography covering the period 1803 to 1939 and consisting of 443 citations with summary statements and indexing according to key words and authors.

012 Chepil, W. S. 1941. Relation of wind erosion to the dry aggregate structure of the soil. Sci. Agr. 21: 448-507.
The minimum wind velocity required to start and continue soil movement was least for particles 0.05 to 0.15 mm. diameter (8-9 mph at six inches above the ground). Above this, threshold velocity increased with increasing grain size. Particles below 0.05 mm were highly resistant to erosion for reasons other than their size or specific gravity. In mixtures containing coarse fractions the movement of erosive material stopped when the surface became protected with coarser materials.

013 Chepil, W. S. and R. A. Milne. 1941. Wind erosion of soil in relation to roughness of surface. Soil Sc. 52: 417-434.
The rate of soil flow under a wind force varies inversely with the roughness of the surface. Ridging cultivated soils markedly reduced rate of soil flow because of reduced wind velocity for some distance above the average soil surface and trapping of soil on the leeward side of the ridges.

014 Chepil, W. S. and R. A. Milne. 1941. Wind erosion of soils in relation to size and nature of the exposed area. Sci. Agr. 21: 479-487.
On a bare fallow, wind erosion may increase with distance as far as 450 yards from the windward edge, due not only to the diminishing shelter effect of the adjacent non-eroded areas but mainly to the cumulative effect of soil drifting. The principal value of alternating stubble strips is their use as barriers which trap moving soil and thus decrease the cumulative intensity of soil drifting.

015 Erdman, R. L. 1942. Effect of wind erosion on the composition and fertility of some Alberta soils. Sci. Agr. 22: 533-545.
Winds, primarily from the south-west in Southern Alberta, are nearly double those of Central Alberta. Productivity of line sandy soil is seriously damaged by wind erosion, silt foams show less injury and clay loams, little injury. Dust samples are about twice as rich in nitrogen and organic matter as the cultivated surface soil from the adjacent area.

016 Chepil, W. S. 1943. Relation of wind erosion to the water-stable and dry clod structure of soil. Soil Sci. 55: 275-287.
Dry clod structure, determined by dry sieving, approximates wind erosiveness. Many soils possessing similar water stable aggregation vary appreciably in clodiness and erosiveness, suggesting that factors other than water stable aggregate structure influences dry clod structure and erosiveness.

017 Chepil, W. S. 1945. Dynamics of wind erosion: I Nature of movement of soil by wind. Soil Sci. 60: 305-320.
Movement in suspension and in surface creep is a result of movement in saltation, therefore erosion control depends on reduction or elimination of saltation. Soil movement is dependent upon wind velocity distribution to the height of saltation. Effectiveness of traps depend on the height and density of the

obstructions and on the resistance of the obstruction to abrasion by the wind-born grains. Soils vary greatly in resistance to abrasion. Grain stubble is virtually unaffected.

018 Chepil, W. S. 1945. Dynamics of wind erosion: II Initiation of soil movement. Soil Sci. 60: 397-411.
Size of soil grains is the greatest single factor determining threshold wind velocity. Threshold velocity for trash is higher than for most erosive grains, but if exceeded and the trash is removed, erosion will continue at wind velocities below the previous threshold velocity. Threshold velocity depends on the history of the field and probably ranges between 13 and 30 mph at the one-foot height above a smooth surface.

019 Chepil, W. S. 1945. Dynamics of wind erosion: III The transport capacity of the wind. Soil Sci. 60: 475-480.
For a given set of soil conditions, rate of soil movement depends mainly on changes in velocity and gustiness of the wind and is only slightly influenced by changes in temperature, air pressure and humidity.

020 Hopkins, E. S., A. E. Palmer and W. S. Chepil. 1946. Soil drifting control in the prairie provinces. Dominion of Canada Dept. of Agr. Publ. 568.
A comprehensive bulletin dealing with the area involved, occurrence, causes, damages, control measures, machinery and interactions with weed and insect control.

021 Chepil, W. S. 1946. Dynamics of wind erosion: IV The translocating and abrasive action of the wind. Soil Sci. 61: 167-178.
Erosion constitutes (1) removal of grains 0.1 to 0.5 mm dia. mostly by saltation, (2) larger grains removed by bombardment, (3) larger grains removed from the peaks of surface projections, (4) finer dust particles that enter temporary suspension and (5) abrasion by wind-born dust and grains in saltation. Prevention and control of wind erosion needs to be based primarily on prevention of movement by the 0.1 to 0.5 size fraction.

022 Chepil, W. S. 1946. Dynamics of wind erosion: V Cumulative intensity of soil drifting across eroded fields.. Soil Sci. 61: 257-263.
Increasing amount of abrasive particles, cumulating degree of abrasion and gradual decrease in surface roughness along the direction of the wind causes gradual increasing soil movement with distance away from the windward edge of eroding fields. Sorting causes coarser material to remain on the windward side of the field and finer material accumulates on the other side. Cumulative amount of erosion with distance is greatest on sandy soils resulting in the need for narrower strips on light soils.

023 Chepil, W. S. 194-6. Dynamics of wind erosion: VI Sorting of soil material by wind. Soil Sci. 61: 331-340.
The wind tends to remove large quantities of fire dust from cultivated fields. The less mobile grains up to 2 mm dia. pile up in dunes or remain in a more or less uniform layer in the vicinity of the eroded area.

024 Chepil, W. S. 1951. Properties of soil which influence wind erosion: V Mechanical stability of structure. Soil Sci. 72: 465-478.
Mechanical stability or relative resistance to breakdown by mechanical agents such as tillage machinery varies directly as the fineness of the soil. Erodibility also varies in direct proportion to mechanical stability.

025 Clark, JOSS. 1951. The costs of soil erosion. Agronews. Agric. Inst. of Can. Ottawa.
Canadian agricultural lands continue to be damaged by erosion. Unfortunately the effects are not usually recognized until losses are so great that there is insufficient soil to sustain profitable productivity. Greater attention must be given to maintaining and improving the inherent productivity of our soils.

026 Anderson, D.T. 1953. Handling straw and trash rover. Mechanical aspects. Agr. Inst. Rev. 8(5): 13-14, 66.
For trash conservation, subsurface cultivators rank first. The blade cultivator conserved as much as 70 percent of the original trash after as many as four operations. The duckfoot cultivator conserved about 60

percent after 2 strokes. Discs bury about 50 percent on each stroke depending on implement, speed and depth of operation. For satisfactory trash conservation while performing adequate cultivation and seeding, the entire sequence beginning with harvest, summer fallow and seeding must be considered.

027 Chepil, W. S. 1953. Factors that influence clod structure and erodibility by wind: I Soil texture. Soil Sci. 75: 473-483.
The coarsest and the finest-textured soils were more erodible than medium-textured soils because they had less well-developed clod structure. The most cloddy and the least erodible soils, other factors being equal, contained about 27 percent clay and the highest silt content.

028 Chepil, W. S. 1953. Factors that influence clod structure and erodibility by wind: II Water-stable structure. Soil Sci. 76: 389-399.
There was an inverse relationship between soil erodibility and percentage water-stable aggregates less than 0.02 mm and greater than 0.84 mm. Water-stable aggregates between 0.05 and 0.42 mm tended to increase erodibility and those between 0.42 and 0.84 tended to reduce erodibility.

029 Johnson, W. E. 1954. Stubble saves the soil. Plant Industry Branch, Saskatchewan Dept. of Agr., Regina.
Do maintain trash cover, strip crop, use forages, seed waterways to grass, use recommended fertilizers and plant shelterbelts. Do not burn stubble, waste manure, pulverize soil, cultivate natural water ways, bury all trash, or operate discs at high speeds.

030 Chepil, W. S. 1954. Factors that influence clod structure and erodibility of soil by wind: III Calcium carbonate and decomposed organic matter. Soil Sci. 77: 473-480.
1 to 5 percent Ca CO caused substantial disintegration of soil clodiness of silt loam and sandy loam and erodibility by wind was increased. Loamy sand clodiness was increased by increased Ca CO content. Decomposed organic matter increased aggregation but only to granules erodible by wind and not larger. Highest erodibility occurred for soils containing high proportions of $Ca\ C0_3$ and decomposed organic matter.

031 Chepil. W. S. 1955. Factors that influence clod structure and erodibility of soil by wind: IV Sand silt and clay. Soil Sci. 80: 155-166.
Clodiness and resistance to wind erosion were greater in soil samples composed of silt than of sand or clay, erodibility being extremely high for sand.

032 Staple, W. J. and J. J. Lehane. 1955. The influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield. Can. J. Agric. Sci. 35: 440-453.
Hedge rows reduce wind velocity to a distance at least 20 times the height of the trees; thus reducing the wind erosion hazard. Evaporation was not reduced very much. Increased wheat yields near the hedges resulted from increased snow trapping.

033 Raney, W. A. and A. W. Zingg. 1957. Principles of tillage. Yearbook of Agriculture. U.S.D.A. Washington, D.C. pp. 277-281.
The soil management practices that are conventionally used in producing crops destroys soil structure. Minimum tillage can overcome this.

034 Chepil, W. S. 1958. Soil conditions that influence wind erosion. U.S.D.A. tech bull. 1185. 40 p.
Intervening rains seldom influence the threshold drag velocity and erodibility of wind eroding soils. When the surface becomes dry, erosion resumes. However, resistance to abrasion is increased by (1) water-stable aggregation, (2) secondary aggregation or clod formation (3) surface crusting and materials among the clods cemented together. Structural conditions and erodibility decreases in summer and increases in winter.

035 Anderson, D. T. 1961. Surface trash conservation with tillage machines. Can. J. Soil Sci. 41: 99-114.

Wide blade cultivators reduce original surface cover by 5, 10 and 15 percent after the first, second and third operations. Rod weeders used for secondary tillage gave similar results. These machines will lift 14 and 11 percent of the original cover back to the surface on fields initially tilled with the one-way disc. The one-way disc and the flexible disc harrow will reduce surface cover by 50 percent during each operation. Trash reduction during primary tillage with the one-way disc increased with increased depth of tillage and decreased with increased amounts of trash cover.

036 Chepil, W. S., N. D. Woodruff and F. H. Siddoway. 1961. How to control soil drifting. Superintendent of Documents. U. S. Gov't. Printing Office, Wash. D. C. Farmers bull. 2169.
Discusses the topic under Primary Causes and Control Measures including stubble mulching, cover crops, strip cropping, crop rotations, machinery, soil blowing and weed control, soil blowing and insect control, windbreaks and other barriers, emergency measures, reclaiming drifting sands and dunes, and community effort and legislation. Causes of soil erosion are strong winds and unprotected, bare, loose, finely granulated soil. Remedial measures are keeping the soil firm and moist, cloddy and roughened, covered with trash, and use of strip cropping and barriers.

037 Johnson, W. E. 1961. Wind and water erosion in Western Canada. Agric. Inst. Rev. 16(3): 12-15.
Sandy-textured and heavy clay soils are particularly prone to wind erosion. Main weaknesses in control programs include inadequate information on productivity losses and surveys of erosion, and research on specific problem areas.

038 McCalla, T. M. and T. J. Army. 1961. Stubble mulch farming, Adv. in Agron. 13: 125-196.
A comprehensive discussion of stubble mulching, defined as the managing of plant residue on a year-round basis to maintain protective amounts of vegetative material on the soil surface until seeding the next crop. The article discusses the soils, crops, machinery, weeds, plant insects and disease aspects of the topic.

039 Bisal, F. and K. F. Nielsen. 1962. Movement of soil particles in saltation. Can. J. Soil Sci. 42: 81-86.
Initiation of movement can be caused by impulsive forces generated by differences in wind velocity and by distribution of particles at the soil surface. In saltation, paths of descent are nearly straight lines with angle of incidence 6 ± 4 degrees.

040 Chepil. W. S., F. H. Siddoway and D. V. Armbrust. 1963. Climatic index of wind erosion conditions in the Great Plains. Soil Sci. Soc. Amer. Proc. 27(4): 449-452.
Based on effective precipitation and wind velocity for a 3-year period ending May 31, the severity of wind erosion can be predicted with considerable certainty for the succeeding crop year. This could form the basis for advice on whether or not special measures should be initiated to control impending wind erosion. But good erosion control practices should always be practiced.

041 Chepil, W. S. and N. P. Woodruff. 1963. The physics of wind erosion and its control. Adv. in Agron. 15: 211-302.
Discusses progress in obtaining new information on wind erosion and control dependent on research and testing. Evidence of progress is that dust storms in the Great Plains during the 1950's were less severe than in the 1930's due to improved technology, more favorable financial resources and greater awareness of the problems.

042 Alberta Soils Advisory Committee. 1964. Soil management in Alberta. Agric. Extension Serv., Dept. of Agric, Edmonton.
The section on wind erosion includes discussion of control practices (trash cover, clod structure, strip cropping, shelterbelts and cover crops); drifting on irrigated land and emergency measures (winter drifting controlled by chiseling, spreading straw or manure or tillage to produce a cloddy condition) and precautions necessary on sandy soils.

043 Anderson, D. T. and G. C. Russell. 1964. Effects of various quantities of straw mulch on the growth and yield of spring and winter wheat. Can. J. Soil Sci. 44: 109-118.
Mulch up to 4000 lbs/ac can be used without detrimental effects on the crop. Quantities of 4000 lbs/ac or more should be managed so that soil temperature depression associated with complete shading of the soil is avoided.

044 Anderson, D. T. 1964. Some factors affecting trash conservation with disc-type tillage implements. Can. Agric. Eng. J. 6: 11-13.
Conservation of trash is maximized when the disc machine is operated at moderate speed, shallow depth and a narrow pan angle, and when clearance between the top of the stubble and the spacer spool is between zero and minus 2 inches. Number of operations is a major factor in trash conservation.

045 Bisal, F. and K. F. Nielsen. 1964. Soil aggregates do not necessarily break down over winter. Soil Sci. 98: 345-346.
If frozen soil first thaws and then dries, erodibility will depend on texture and water content. If freeze-dried, the soil becomes much more erodible.

046 Dryden, R. D., W. K. Dawley and K. W. Hill. 1964. Control of soil drifting in south western Manitoba. Canada Dept. Agric. publication 1178.
A report on methods of reclaiming the eroded land in south western Manitoba and growing crops satisfactorily. Describes the soils and weather and soil management methods including free shelterbelts, strip farming, cover crops, tillage precautions, trash cover, summerfallow substitutes and the soil fertility implications.

047 Holm, H. M. 1964.
Save the soil. A study in soil conservation and erosion control. Plant Industry Branch, Sask. Dept. of Agr., Regina. An earlier version of Holm, H. M. 1982. Save the soil.

048 Anderson, D. T. 1965. Some factors affecting trash conservation with subsurface cultivators. Can. Agric. Eng. J. 7: 45-46, 49, 56.
The heavy-duty cultivator with rod weeder attachment conserved 12 percent more trash after 2 operations than the cultivator alone. Best conservation of trash occurs with shallow tillage and moderate speed. Severe burial of trash (up to 60 percent) occurs when soil is firm and moist, little burial when soil is fairly dry and unconsolidated.

049 Black, A. L. and J. F. Powers. 1965. Effect of chemical and mechanical fallow methods on moisture storage, wheat yields and soil erodibility. Soil Sci. Soc. Amer. Proc. 29: 465-468.
Some problems with chemical fallow such as ungerminated weed seeds causing infestation of the following crop caused wheat yields to be less for chemical fallow than for stubble mulch mechanical fallow. But wind erodibility was lower on the chemical fallow and chemical fallow retained 10 percent more surface trash.

050 Anderson, C. H. and A. Wenhardt. 1966. Soil erodibility fall and spring. Can. J. Soil Sci. 46: 255-259.
Wood Mountain clay loam was significantly less erodible in the spring than in the previous fall, indicating overwinter aggregation of the erodible fraction of the soil.

051 Anderson, D. T. and A. D. Smith. 1966. Seeding mechanisms for trashcover farming. Can. Agric. Eng. 8: 35-36.
The wide-blade cultivator has limited usefulness as a combined seeder. The one-way disc seeder gave good results where trash did not exceed 4000lbs/ac. Double-disc drills may be inferior where trash exceeds 2000lbs/ac. The semi-deep furrow drill is as good as the one-way disc seeder in trash up to 4000lbs/ac.

052 Anderson, D. T. (chairman) and Committee. 1966. Soil Erosion by Wind. Cause, damage, control. Can. Dept. Agr. Publ. 1266. 26p.

Topics discussed include: how soil drifting occurs; control measures such as trash cover, clod production, harvest equipment, seeding equipment, minimum tillage, strip cropping, cover crops, rotations, shelterbelts, and emergency measures; soil drifting on irrigated land, specialty crop land, and pastures and range lands.

053 Bisal, F. and J. Hsiek, 1966. Influence of moisture on erodibility of soil by wind. Soil Sci. 102: 143-146.
The small amounts of moisture required to make a soil resistant to movement by wind can be removed in a short time, causing the soil to be highly erosive if it is of an erosive size range.

054 Soil Conservation Service. 1966. Facts about wind erosion and dust storms on the great plains. U.S.D.A. leaflet 394. U. S. Gov't. Printing Office, Wash., D. C.
"All who till or graze the Great Plains must adopt good land use and soil and water conservation practices and plan for recurrent droughts to have a permanent and profitable agriculture, The alter native is bigger and worse 'dust bowls' with each succeeding drought. And there will be more droughts because these are a normal feature of the climate of this region."

055 Anderson, D. T. 1967. The cultivation of wheat. K. F. Nielsen (ed.) Can. Centennial Wheat Symposium. Univ. of Sask., Saskatoon, Sask.
Cultivation has changed from plowed to plowless. Fallow is cultivated only as often and as deep as required to control weeds. Protection from wind erosion is obtained mostly with cultivators to conserve trash cover. Weed control and erosion protection led to early acceptance of the concept of minimum tillage. Herbicides potentially increase erosion protection because trash cover can be protected.

056 Anderson, D. T. 1967. Factors affecting trash conservation with the wide blade cultivator. Can. Agr. Eng. 9: 98-100 and 127.
Percent trash conservation tended to be greater when the residue contained short stubble than long stubble. Differences were small after three operations. High speed (5 mph) during primary tillage helped straw clear the standards and less trash was buried than at moderate speed (3 mph). Depth of tillage had no influence on percent conservation but shallow depth loosened the stubble more than deep during the third operation. Stubble may be completely flattened by more than three operations.

057 Molberg, E. S., E. V. McCurdy, A. Wenhardt, D. A. Drew and R. D. Dryden. 1967. Minimum tillage requirements of summerfallow in Western Canada. Can. J. Soil Sci. 47: 211-216.
At 7 locations in Western Canada between 1956 and 1961, 3 or 4 tillage operations controlled weeds on summerfallow; 2 were not enough. Herbicides without tillage did not entirely control weeds and slightly less moisture was conserved.

058 Pelton, W. L. 1967. Effect of a windbreak on wind travel, evaporation and wheat yield. Can. J. P1. Sci. 47: 209-214.
Snow fencing, erected after seeding in the spring reduced wind travel by 49 percent close to the fencing and by 15 percent leeward to a distance 20 times the height of the fence.

059 Anderson, C. H. 1968. A comparison of annual crops for seed and residue in the semi-arid region of Western Canada. Can. J. Pl. Sci. 48: 287-292.
In amount of crop residue produced: oats was greatest, wheat, barley and rapeseed equal, and mustard, flax and peas least. But after the 21-month summerfallow period, wheat, oats and barley were equal and greater than mustard, rapeseed, flax or peas. Only the cereals provided adequate residues for control of wind erosion.

060 Anderson, D. T. 1968. Some qualitative effects of tillage machines on plant residues used for erosion control. Can. Ag. Eng. 10:53-56.
With the wide blade cultivator, speed of operation, depth or stubble height did not affect the progressive loosening effect on residue. Results for the heavy-duty cultivator were similar, except high speeds (5 mph) in readily pulverized soil loosened most stubble during the second operation. The rod weeder loosened 90 percent of all residue in two operations. Stubble was usually left standing after two

operations of the one-way disc but flattened by the third. With the disc, loosening was greater for shallow than for deep discing. Tall stubble was loosened and flattened by deep discing.

061 Bisal, F. 1968. Influence of plant residue on sand flow in a wind tunnel. Can. J. Soil Sci. 48: 49-52.
In a wind tunnel small amounts of stubble had little effect on sand movement, followed by a rapid decrease in movement with increased amount of stubble. Movement approached zero at stubble amounts of 1200 kg/ha for 5.36 m/sec wind to 7200 kg/ha for 8.49 m/sec wind.

062 Bisal, F. and W. S. Ferguson. 1968. Monthly and yearly changes in aggregate size of surface soils. Can. J. Soil Sci. 48: 159-164.
Over a 12-year period there was a high monthly and yearly variation in the percent of total aggregates greater than 0.84 mm dia. by dry sieve analysis. The greatest variation occurred in the clay soil. The value of dry sieving to predict susceptibility to erosion over extended time is limited.

063 Dew. D. A. 1968. Effect of summerfallow tillage on soil physical properties and yield of wheat. Can. J. Soil Sci. 48: 21-26.
On a Black loam soil in central Alberta tillage beyond that required to control weeds did not increase wheat yields and had little effect on soil moisture conserved and wind erodible aggregates.

064 Palmer, A.E. 1968(circ.). When the winds came. How the battle against soil drifting was won on the Canadian prairies. Published by A. E. Palmer, Lethbridge.
An historical sketch of the development and conquering of the problems of soil drifting on the Canadian prairies with a section on the life and accomplishments of Dr. Charles S. Noble, developer of the Noble blade cultivator. "With us in the 1930s it was a matter of finding what to do. Now it requires only doing that which has been well tried and found to be good. There is no longer an excuse for permitting the soil to blow away. Any soil drifting is a result of carelessness, misjudgement or poor planning and is a mark of some form of poor husbandry" - A. E. Palmer.

065 Radio and Information Branch. 1968. Soil drifting danger cited. Alberta Dept. of Agric., Edmonton. Dec. 11.
In years of above rainfall weeds are not readily controlled by the cultivator or blade implements normally used in trash conservation cultivation. Then, when farmers are forced to go over fields 5 or 6 times to obtain good weed kill, trash is destroyed and soil erosion may result.

066 Anderson, C. H. and F. Bisal. 1969. Snow cover effect on the erodible soil fraction. Can. J. Soil Sci. 49: 287-296.
With continuous snow cover there was a decline in percent aggregates less than 1 mm dia. over winter, with a marked decline during spring thaw. Without snow the exposed soil became very erosive. There were important water losses by sublimation during deaggregation.

067 The United Grain Grower. 1969. How to prevent wind erosion. United Grain Growers, Winnipeg, Man.
Trash cover farming is keeping a cover of straw and stubble and a cloddy surface on the soil. Methods - leave tall stubble, spread the straw, use implements that preserve the trash and produce a lumpy surface, strip crop, use cover crops, use grasses and legumes, reduce fallow, and plant shelter belts. Emergency measures - chiselling, strip listing or plowing to turn up lumps, spread straw or manure at focal points and lightly disc it in. Soil drifting can be especially important on irrigated land because most irrigated crops leave little or no trash cover and the soil is usually in poor and fine condition.

068 Bisal, F. and W. S. Ferguson, 1970. Effect of non-erodible aggregates and wheat stubble on initiation of soil drifting. Can. J. Soil. Sci. 50: 31-34.
log I = 6.0438 + 0.0001724S + 0.02332C where I = initiating wind velocity ^{e}(cm/sec) measured at 30.5 cm above the soil surface, S = standing wheat stubble 15 cm high (kg/ha) and C = percent of soil aggregates greater than 1 mm dia. The wind velocity required to initiate erosion is proposed as an index of erodibility of farm fields.

069 Marlott, W. E. and D. W. Huder.1970.
Soil ridging for reduction of wind erosion from grass seed beds. J. Range Mgt. 23: 170-174. Ridging a sandy loam soil by packing with a heavy packer wheel prevented wind erosion from a modified seed bed. High intensity rain and hail can eliminate the ridges.

070 Siddoway, F. H. 1970. Barriers for wind erosion control and water conservation. J. Soil and Water Conserv. 25: 180-184.
The interaction of vegetation barriers with wind and water can be an asset or liability on farms and ranches in the Great Plains, depending on barrier size and location.

071 Smalley, I. J. 1970. Cohesion of soil particles and the intrinsic resistance of simple soil systems to wind erosion. J. Soil Sci. 21: 154-161.
Because tensile strength is inversely proportional to the cube of the particle size, any decrease in particle size produces a great increase in tensile strength. But the particles are lighter once disturbed and so are more easily eroded.

072 Anderson, C. H. 1971. Comparison of tillage and chemical summerfallow in a semi-arid region. Can. J. Soil Sci. 51: 397-403.
Chemical weed control equalled cultivation in soil moisture conservation, soil temperature and yield of wheat. Chemical summerfallow conserved 62 percent of the original crop residue, cultivated fallow, 35 percent. Chemical fallows were less erodible (fewer particles less than 1 mm dia.) at the completion of tillage in autumn but chemical fallows had the best aggregation over winter.

073 Black, A. L. and F. H. Siddoway, 1971. Tall wheatgrass barriers for soil erosion control and water conservation. J. Soil and Water Conserv. 26: 107-111.
The use of double-row perennial grass barriers could permit extensive farming with more flexibility in cropping practices, selection of crops grown and soil management practices without the continual threat of wind erosion.

074 Meredith, D. 1971. Ounce of prevention can prevent wind damage. Soil Conserv. 36(7):155.
On sugar beet fields, strips of grain can be planted in the fall to give protection to the beet crop.

075 Toogood, J.A. 1971. Strip farming for wind erosion control in Alberta. Agric. Bull. No. 16. Univ. of Alta. Edmonton. pp.3-5.
Includes maps showing areas in Alberta where strip cropping was practiced between 1961 and 1965, and average annual wind velocity, record hourly velocity and record gust.

076 The United Grain Grower. 1971. Trap snow and stop erosion with strips of tall wheatgrass. United Grain Growers. Winnipeg, Manitoba.
Describes the use of two rows of tall wheatgrass spaced about 3 feet apart with each barrier 30 to 50 feet apart across a field and at right angles to the prevailing winds.

077 Hagen, L.J. et al. 1972. Designing narrow strip barrier systems to control wind erosion. J. Soil and Water Conserv. 27: 269-272.
The percentage of soil entering a barrier strip that is retained depends on barrier height, width and wind speed. Two-rod barriers provided the best trapping efficiency. If trapped soil reduces trapping efficiency, barrier spacing must be reduced.

078 Lyles, L. and R.L. Schrandt. 1972. Wind erodibility as influenced by rainfall and soil salinity. Soil Sci. 114: 367-372.
In the laboratory, loss by wind from sodium-chloride treated soil was less than from a non-saline soil or from soil treated with other salts. Soil loss following low intensity rain was less than following high intensity rain. Rainfall duration did not significantly affect soil loss.

079 Woodruff, N. P. et al. 1972. How to control wind erosion. U.S.D.A Agri. Info. Bull. 354.

A comprehensive discussion covering the following topics: How wind erosion occurs, factors affecting wind erosion, the wind erosion equation, principles of control, control on dryland, cultivated soils, control on irrigated land, control on vegetable and specialty crop lands, control on grazing lands, control on sand dunes and other areas and precautions.

080 Amburst, D. V. et al. 1974. Physiological responses to wind- and sand-blast-damaged winter wheat plants. Agron. J. 66: 421-42.3.
Reduced growth of sand-blasted wheat seedlings is caused by loss of viable leaf tissue and physiological changes which are mainly reduced photosynthesis and increased respiration. It was not clear whether these changes result from partial defoliation, short-tern high intensity moisture stress, or both.

081 Fryrear, D. W. and C. L. Wiegand. 1974. Evaluating wind erosion from aerial photos. Am. Soc. Agric. Eng. Trans. 17: 892-894.
More research is needed to determine the wave band that best describes soil surface erodibility. Precise ground truthing or correlation of density tracings with photographic images is needed for interpretation.

082 Simmons, S. R. and A. D. Dotzenko. 1974. Proposed indices for estimating the inherent wind erodibility of soils. J. Soil and Water Conserv. 29: 275-276.
In Colorado soils, cation exchange capacity and 15-bar moisture percentage as indicators of the nature of the soil inorganic-organic colloidal complex, were good indicators of the inherent erodibility of a soil.

083 Anderson, C. H. 1975. A history of soil erosion by wind. Research Branch, Canada Dept. of Agriculture. Historical series no. 8.
A case study - the reason for the soil erosion problems of Western Canada was the rapid introduction of a cultural system not adapted to the ecological environment coincident with periods of low precipitation, high winds, insect and plant disease outbreaks and economic distress. All levels of government and farmer co-operation were required to bring soil drifting under control. Strong research and effective extension must continue.

084 Anderson, D. T. 1975. Summerfallowing and the soil drifting hazard. Weekly Letter no. 2180. Agriculture Canada Research Station, Lethbridge, Alberta.
"Westerly winds swept across southern Alberta and reached speeds of 55 mph at Lethbridge on Saturday, October 4. In several farm fields tons of topsoil billowed skyward in destructive protest against a lack of wind protection. Many fallow fields cropped in narrow strips, snuggled contentedly under a protective blanket of trash cover, of good clod structure or (in some cases) of a well-developed cover crop".

085 Fryrear, D. W. and J. D. Downes. 1975. Consider the plant in planning wind erosion control systems. Amer. Soc. Agric. Eng. Trans. 18: 10701072.
Eight crops were rated for resistance to damage by windblown sand in a wind tunnel. For 80 percent survival of 6 day old plants, peppers were the most tolerant and tomatoes the least.

086 Lindwall, C. W. 1975. The conservation characteristics of minimum tillage practices. M. Sc. thesis, U. of A., Edmonton, Alberta.
Fallows with chemical weed control conserved more crop residue than cultivated fallows and maintained the highest soil moisture status. One-way discing conserved the least crop residue and left the fallows susceptible to wind erosion.

087 Lyles, L. 1975. Possible effects of wind erosion on soil productivity. J. Soil and Water Conserv. 30: 279-283.
In Kansas, annual yield reductions of 339,000 bushels of wheat and 543,000 bushels of grain sorghum occur on 1.2 million acres of sandy surface soils.

088 Lyles, L. and B. E. Allison. 1975. Wind erosion: uniformly spaced non-erodible elements eliminate effects of wind direction viability. J. Soil and Water Conserv. 30: 225-226.

Equidistant spacing of non-erodible elements (eg. plants at various populations) provides equal protection from wind erosion regardless of wind direction. The protection equals that of elements in rows oriented normally to wind direction (row spacing not more than 61 cm.) and assuming equal numbers of elements per unit area for any orientation.

089 Seevers, P. M. et. al. 1975. Use of ERTS-1 imagery to interpret the wind erosion hazard in Nebraska sand hills. J. Soil and Water Conserv. 30: 181-183.
Images in the visible red wave length made possible construction of maps showing blow-out distribution and areas where the range was likely susceptible to wind erosion.

090 Black, A. L. and F. H. Siddoway. 1976. Dryland cropping sequences within a tall wheatgrass barrier system. J. Soil and Water Conserv. 31: 101-105.
At Sidney, Montana, tall wheatgrass barriers (2 rows, 36 inches apart at 48-foot spacing) controlled wind erosion and conserved enough snow-water to make continuous cropping feasible.

091 Lindwall, C. W. 1976. Emergency control measures in preventing wind erosion. Press Release Feb. 27. Agric. Canada Res. Sta., Lethbridge, Alberta.
Wind erosion is a continuing threat. Control measures include chiselling at right angles to the wind, listing with lister shovels or with 6 inch chisel blades on the standards of a wide blade cultivator, and spreading manure or straw.

092 Lyles, L. and B. E. Allison. 1976. Wind erosion: the protective role of simulated standing stubble. Amer. Soc. Agric. Eng. Trans. 19: 61-64.
Stubble rows normal to wind direction provided 1.4 to 2 times the protection from wind erosion provided by rows parallel to wind direction. On a weight basis 5.5 to 8.7 times more sorghum or corn stubble than wheat stubble was required to provide the same erosion protection.

093 Pimentel, D. et al. 1976. Land degradation: Effects on food and energy resources. Science 194: 149-155.
A discussion of the effect of soil erosion and degradation on supplies of food in the U.S.A. and world-wide. Some points: crop yield losses per inch of topsoil lost - corn, 4 bu/ac/yr; oats, 2.4 bu/ac/yr; wheat, 1.6 bu/ac/yr; soybeans, 2.6 bu/ac/yr. An estimated 200 million acres have been either totally ruined for crops or is rendered very marginal by erosion in the U.S.A. World-wide, environmental degradation of land is worse than in the U.S.A.

094 The United Grain Grower. 1976. Build this zero-tillage attachment for your drill. United Grain Growers, Winnipeg, Manitoba.
Gives materials, costs and labor required to add coulters ahead of the double disc furrow openers of a grain drill for better action in planting grain on trash-covered fields.

095 Crown, P. H. 1977.
Another look at strip farming in Southern Alberta. Agriculture and Forestry bulletin. Fall issue. U. of A., Edmonton. Includes a map showing the extent of strip farming in Southern Alberta as shown by Landsat imagery.

096 Lindwall, C. W. and D. T. Anderson. 1977. Effects of different seeding mechanisms on spring wheat production under various conditions of stubble residue and soil compaction in no-till rotations. Can. J. Soil Science 57: 81-91.
Double and triple-disc drills may not penetrate untilled surfaces adequately when soil bulk density to 5cm. depth exceeds 1.2 g/cm^3 or when crop residue exceeds about 3700 kg/ha. Hoe openers penetrated the soil but plugged when stubble and straw lengths were greater than 25 cm.

097 Toogood, J. A. 1977. Wind and water erosion problems in Alberta. Soil Conservation Reclamation and Research. Proc. of the Alberta Soil Sci. Workshop. Feb. 1-2. Alberta Agriculture, Edmonton, Alberta.

Our wind erosion problem is not solved and our water erosion problem is being neglected. Maps are given that show hours per year when wind velocities exceed 32 mph, rainfall, and areas where special care is required to prevent serious wind erosion.

098 The United Grain Grower. 1977. No-till drills available for spring seeding. Farm Information Service, United Grain Growers, Winnipeg, Manitoba.
Illustrated are 8 makes of drills that can be used for no-till seeding.

099 Alberta Agriculture. 1978. Wind erosion and its control. Agdex 573-4. Communications Branch, Alberta Agriculture, Edmonton, Alberta.
Soil drifting which began when prairie was first brought under cultivation, became severe during the 1920s and 1930s, and there have been years of serious wind erosion since that time. Soil drifting deteriorates the soil and causes crop loss. It starts at focal points and spreads, is caused by high winds when the soil is exposed, fine and dry. It must be controlled by trash cover, strip cropping, shelter belts, cover crops and maintaining high soil organic matter and a cloddy structure. Emergency measures include chiselling, ripping or spreading straw.

100 Baldwin, C. S. and C. J. Acton. 1978. Soil erosion by wind - nature and extent. Notes on Agriculture 14(3). pp 8-9. Ontario Agriculture College, Guelph, Ontario.
In Southern Ontario an estimated 400,000 ha have a high potential for wind erosion. Erosion of soil by wind causes losses of productivity and annoyance and danger to the public. There is a continuing need for preventive measures.

101 Plant Industry Branch and Ag. Eng. Services Section, Family Farm Improvement Branch. 1978. Zero tillage. Sask. Dept. of Agric., Regina, Sask.
Zero tillage is not adapted to all soils and areas. More research is needed on (1) seed drills, (2) use of anhydrous ammonia, (3) phosphorus application, (4) soil compaction, (5) cheaper herbicides and (6) crop rotations.

102 Sperbech, Jack. 1978. Saving our topsoil. Minnesota Science. Univ. of Minn. St. Paul, Minn. 33: 3-5.
"Too much topsoil is being lost from some Minnesota soils and if the trend isn't reversed, soil losses spell trouble for farmers and consumers alike." "Below that thin layer composing that delicate organism known as the soil is a planet as lifeless as the moon." - G. V. Jacks and R. 0. Whyte. Vanishing Lands, a World Survey of Soil Erosion. 1973.

103 Zentner, R. P. and C. W. Lindwall. 1978. Minimizing summerfallow tillage with herbicides. Weekly letter 2307. Agric. Canada Research Sta., Lethbridge, Alberta.
The use of some herbicides in the fallow year has potential economic advantages and substitution of herbicides for mechanical tillage seems advisable to reduce soil erosion and moisture loss.

104 Zentner, R. P. and C. W. Lindwall. 1978. An economic assessment of zero-tillage in wheat-fallow rotations in Southern Alberta. Can. Farm Econ. 13(6): 1-6.
In addition to improvements in moisture conservation, erosion resistance and grain yields, substantial savings in labor, fuel and oil, machine repairs and overhead costs can be achieved by zero tillage. Adoption will depend on individual farm characteristics and the relation of cost of effective herbicides to the savings and increased yield values.

105 Cameron, D. R. 1979. Conventional, minimum and zero-tillage. Weekly Letter. Jan. 12. Agric. Canada Research Sta. Swift Current, Sask.
In 1978, there were no differences between the yields on conventional tillage and zero-till crops in a recropping situation.

106 Lindwall, C. W., R. P. Zentner and D. T. Anderson. 1979. Conservation characteristics of minimum tillage systems. Paper no. 79-1019. Meeting of A.S.A.E. and C.S.A.E., Winnipeg, Man. June 24-27.

In 8 summerfallow systems for spring wheat production, minimum tillage improved moisture conservation, lowered energy inputs and increased yields, but repeated application of herbicides is riot presently economical.

107 Skidmore, E. L. et al. 1979. Crop residue management for wind erosion control in the Great Plains. J. Soil and Water Conserv. 34: 90-94.
Grain crop residues are a valuable resource for soil conservation and removal should be done judiciously with an understanding of the consequences.

108 Agric. Inst. of Canada. 1980. Soil erosion on agricultural land in Canada. Agrologist 9: 23-28.
Although wind erosion is currently considered to be less severe than water erosion in Canada, the problem can become severe, particularly since some new management techniques tend to de-emphasize some of the established wind erosion control systems of soil management. A research educational program is needed.

109 Anonymous. 1980. What soil and water erosion costs you. Grass Roots News and Views. Foothills Forage Crops Assn., Calgary, Alta.
The report of a 1980 task force summarizes losses due to soil and water erosion: Crop yields are reduced about 3.4 bu/a/inch of topsoil eroded. Wind eroded soils in Saskatchewan have yields reduced 70 percent compared to non-eroded soils. Fertility losses from eroding agricultural fields may represent an annual loss of $37 to $74 per acre. Cropping values of the land may be dropped from Class I and II to lower classes.

110 Anonymous. 1980. Zero tillage. Agdex 516-1, Print Media Branch, Alberta Agriculture, Edmonton.
A review of the main information available to date covering capital investment, yields, fertilizers, hazards, operations, research and economics. In the Brown soil zone, zero and minimum till must promote increased yields in addition to decreased labor and other costs to provide the same return as 50 percent summerfallow with mechanical tillage.

111 Cameron, D. R. 1980. Zero tillage - is it worthwhile? Weekly Letter July 11, Agric. Canada Res. Sta., Swift Current, Sask.
The cost of weed control is the primary drawback. The demand on time is great and timing is critical. In zero tillage lower cost of tillage equipment may be offset by the requirement for heavy drills and spraying equipment plus herbicide costs.

112 Lindwall, C. W. 1980. The value of topsoil. Weekly Letter 2411. Agric. Canada Res. Sta., Lethbridge.
After 22 years and 14 crops, with annual applications of fertilizer, the productivity of "eroded" soil (20 cm of topsoil removed) has improved but not fully restored. At 1980 prices the difference in net returns from undisturbed and "eroded" soils averaged $100/ac/year.

113 Lindwall, C. W. 1980. Zero and minimum tillage. Agrologist 9(1): 9-10.
Interest in zero and minimum tillage is increasing in Canada and the benefits of wind erosion control and increased yields have been demonstrated. But drawbacks include high cost of herbicide and lack of suitable machinery. Special drills have been and are being developed to overcome the difficulty of seeding into untilled soil.

114 Lyles, L. and B. E. Allison. 1980. Range grasses and their small grain equivalents for wind erosion control. J. Range Mgt. 33: 143-146.
Compared with flat small grain, range grasses effectively prevented erosion with buffalo grass (Buchloe dacloides) the most effective and big bluestem (Andropogon gerardi) the least effective of those tested.

115 McDole, R. E. and S. Vira. 1980. Restricted summerfallow for soil erosion control under dryland crop production. College of Agriculture Univ. of Idaho, Moscow, Idaho. Current Information Series no. 522.

Summerfallow is unnecessary when precipitation is more than 16 inches per year. Summerfallow is a major contributor to soil erosion under dryland cropping and unnecessary fallowing should be eliminated.

116 McDole, R. E. and S. Vira. 1980. Minimum tillage for soil erosion control under dryland crop production. College of Agriculture, Univ. of Idaho, Moscow, Idaho. Current Information series no. 523.
The greatest advantage of minimum tillage is the prevention of soil erosion. For each inch of topsoil lost, wheat yields are reduced 2.5 to 3 bu/ac/yr.

117 Staff of the National Association of Conservation Districts. 1980. Soil degredation: Effects on agricultural productivity. National Association of Conservation Districts., Washington, D.C.
"There is a limit to the extent to which applied science can temporarily force up soil productivity but there is no limit except zero to the extent which erosion permanently reduces it." The paper discusses natural loss of soil productivity, soil erosion by water and wind, soil compaction and deterioration of soil structure, soil water problems including diminishing water supplies, increasing salinity and alkalinity, waterlogging of productive soils, air pollution and its impact on soils, and soil problems in urbanizing areas.

118 Anonymous. 1981. Erosion robs soil fertility. Agdex 572. Communications Branch, Alberta Agriculture, Edmonton, Alberta.
In Manitoba analysis of soil samples show that much soil fertility is lost to wind erosion. The nitrogen is obviously bound to the lighter soil particles and organic matter which is the very material subject to loss through wind erosion.

119 Biederbeck, V. 0., J. A. Robertson and D. C. McKay. 1981. Influence of management practices on degradation. Agriculture Land: Our Disappearing Heritage. Proc. Alta. Soil Sci. Workshop. pp. 256-320.
Introduction of arable agriculture disrupted the steady state conditions of Western Canadian soils. Erodibility was increased by tillage through hastened decomposition of organic matter, exposure, adoption of summerfallow, removal of crop residue or its burial by plowing, and use of implements that pulverize the soil. The recent increasing width of strips may re-initiate severe wind erosion. Over the years farmers and researchers have developed practices that will retard or prevent further soil deterioration if implemented.

120 Cameron, D. R., C. Shaykewich, E. de Jong, D. Chanasyk, M. Green and D. W. L. Read. 1981. Physical aspects of soil degradation. Agricultural Land: Our Disappearing Heritage. Proc. Alta. Soil Sci. Workshop. pp. 186-255.
The primary effect of cultivation has been the physical effect of pulverization. In addition to enhancing loss of organic matter and fertility, cultivation has destroyed surface cover and produced smaller and less stable aggregates resulting in soils being susceptible to water and wind erosion.

121 Didericksen, R. I. 1981. Resource Inventory: sheet, rill and wind erosion. Amer. Soc. Agric. Eng. Trans. 24: 1246-1252.
In 1977 an estimated 209 million hectares in the 10 Great Plains states were eroded by wind with an average loss of 11.9 t/ha. 61 percent occurs on cropland, 38 percent on rangeland. Losses vary from 2.9 to 33.4 t/ha.

122 Fryrear, D. W. 1981. Dust storms in the Southern Great Plains. Amer. Soc. Agric. Eng. Trans. 24: 991-994.
Using climatic data for the last 1/3 of the year, the number of dust storms at Big Spring, Texas can be estimated 12. months in advance, within 4 days 56 percent of the time and within 8 days 82 percent of the time. New farm implements are needed to combat wind erosion.

123 Goettel, A. W., J. C. Hermans and D. R. Coote. 1981. Degradation by erosion. Agricultural Land: Our Disappearing Heritage. Proc. Alta. Soil Sci. Workshop. pp. 134-158.
To meet expected domestic and export requirements, Canadian grain production will need to increase by 50 percent by 1990. Some of this increase may come from production on poor quality land resulting in an

increased risk of soil erosion. But there also may be more recropping and erosion may be reduced by a reduction in summerfallow.

124 Lindwall, C. W. and D. T. Anderson. 1981. Agronomic evaluation of minimum tillage systems for summerfallow in Southern Alberta. Car. J. Plant Sci. 61: 247-253.
Herbicides were as effective as tillage to control weeds during the summerfallow season. Crop residue and soil moisture conservation were greater when weeds were controlled by herbicides than by machine cultivation. Chemicals conserved 67 percent of the original crop residue, compared with 43 percent for bladed fallow.

125 McGill, W. B., C. A. Campbell, J. T. Dormaar, E. A. Paul and D. W. Anderson. 1981. Soil organic matter losses. Agricultural Land: Our Disappearing Heritage. Proc. Alta. Soil Sci. Workshop. pp, 72-133.
Prairie soils have lost a minimum of 35 to 50 percent of their organic matter. The greatest loss has been in the Black soil zone. The implications are: (1) loss of nutrient supplying power, (2) deterioration of soil physical properties, (3) environmental problems relating to climate. Erosion and soil organic matter losses are linked through a positive feedback system. Erosion selectively removes organic-rich materials and the loss of these materials increases susceptibility to further erosion. High productivity has a positive feed back on soil organic matter maintenance. Any input mechanism that increases productivity will increase organic matter. One of the best ways to add organic matter is through plant roots.

126 Nicholaichuk, W. 1981. What about snow management? Weekly Letter Nov. 6. Agr. Can. Research Sta., Swift Current, Sask.
Snow ridging gives modest benefits in only 2 of 5 years. Swathing at alternate heights also traps snow. Single rows of tall wheatgrass offer a potential for exceeding the moisture gain when compared to summerfallow. Strips of tall standing stubble shows promise.

127 The United Grain Grower. 1981. Economics of snow management. United Grain Growers. Winnipeg, Manitoba.
Barriers may be classed as non-competitive, which include snow ridging and swathing at alternate heights; and competitive which include shelterbelts and grass barriers.

128 Anonymous (date unknown) A guide to zero till farming. Alberta Agriculture, Edmonton.
A guide only for those farmers who are already involved or wish to become involved in zero tillage in Alberta and containing selected articles from Manitoba, Saskatchewan and Alberta.

129 Caprio, J. M., G. K. Grunwald and R. D. Snyder. 1982. Snow barrier potential for harvesting moisture in transects across chinook areas in Montana. Res. Rept. 175. Montana Agric. Expt. Sta. Montana State University, Bozeman, Montana.
Snow depth is greater in stubble than on fallow and the stubble is relatively more effective during winters with less amounts of precipitation. The relative depth of snow, stubble to fallow, was greater in chinook areas than in non-chinook areas. Maximum benefit appears to occur with low winter precipitation of about 5 cm and this precipitation amount is associated with about an additional 3 to 4 cm of moisture entering the soil.

130 Cook, K. 1982. Soil loss: a question of values. J. Soil and Water Conserv. 37: 89-92.
The applications of "T values" (soil loss tolerance values) are discussed along with the difficulties and pitfalls in attempting to set T values. It is shown that the calculated costs of soil erosion to the farmer and to society may be widely erroneous.

131 Davidson, P. 1982. The '30s may be gone but soil erosion continues. Print Media Branch, Alberta Agriculture, Edmonton.
Although not so evident as in the '30s, soil erosion is still a serious problem. Summerfallowing, destruction of grassed areas and fall incorporation of herbicides have been largely responsible. Minimum tillage management methods will help. Education and research are needed.

132 Dregne, H. E. 1982. Impact of land degradation on future world food production. ER 5-677. Economic Research Service, U.S.D.A. Washington, D.C.
Forty percent of the worlds available land is being farmed, representing the best soils. Cultivating the remaining marginal 60 percent will be expensive and require new technology. Canada is comparatively free of land desertification in comparison to other areas of the world.

133 Holm, H. M. 1982. Save the soil. A study in soil conservation and erosion control. Plant Industry Branch. Saskatchewan Agriculture, Regina. Sask.
Steps to successful soil conservation are: Basic knowledge, Trash conservation, Fertilizers and manures, Strip cropping, Field shelterbelts, Contour strip cropping, Grassed waterways and mechanical aids, cover cropping and grasses and legumes in the farm rotation.

134 Jenkins, C. 1982. Soil erosion costs explained by expert. Weekly Manitoba Co-operator.
"The Soils Research Institute of Agriculture Canada estimates that erosion actually costs about $20.40 per tonne of soil lost."

135 McGill, W. B. 1982. Soil fertility and land productivity in Alberta. EC A82-17/1B16. Environment Council of Alberta. 132 pp.
"… tillage benefits the immediate growth of crops and helps control weeds. At the same time, however, it jeopardizes stability of the whole soil system such that long time productivity could diminish to zero in extreme cases (such as in parts of Oklahoma). Balancing these two opposing outcomes from tillage is the aim of present research and some innovative farm practices."

136 Brown, L. R. 1982. R & D for a sustainable society. American Scientist 70(1): 14-17.
One-fifth to 1/3 of the worlds cropland is losing topsoil at a rate that is undermining long term productivity. The inherent productivity of 34 percent of U.S. cropland is falling because of loss of topsoil.

Key Words	Bibliographic File Numbers
<u>Soil</u>	
Aggregation	012, 016, 017, 018, 020, 021, 023, 024, 027, 028, 030, 031, 034, 039, 045, 050, 062, 063, 066, 068, 071, 072.
Cloddiness	002, 016, 017, 018, 021, 024, 027, 028, 030, 031, 033, 034, 042, 067, 084, 099.
Crusting	033, 034.
Erodibility	002, 007, 008, 012, 013, 014, 016, 017, 018, 019, 021, 022, 023, 024, 027, 028, 030, 031, 034, 038, 045, 050, 053, 061, 062, 063, 066, 067, 068, 071, 072, 078, 081, 082, 089, 090, 114,116,120.
Herbicides	055, 057, 101, 103, 106, 113, 124,131,133.
Irrigated	042, 067.
Moisture	002, 006, 034, 045, 053, 055, 065, 066, 069, 078, 082, 090, 097. 099, 106, 115, 129, 133.
Organic Matter	015, 023, 038, 082, 118, 120, 125.
Texture	002, 007, 008, 015, 017, 018, 021, 022, 023, 024, 027, 031, 037, 039, 042, 045, 050, 053, 062, 097, 118, 133.
Zones	063, 097.
<u>Wind</u>	
Gusts	019, 075.
Map	075, 097, 099.
Prevailing	002, 015, 075, 076, 091, 129, 113.
Velocity	006, 012, 013, 015, 017, 018, 019, 021, 032, 039, 058, 061, 068, 075, 076, 077.

Key Words	Bibliographic File Numbers
Processes	
Abrasion	017, 021, 022, 080, 085.
Dust	021, 023.
Freeze-dry	045, 066.
Saltation	010, 017, 021, 039.
Sorting	021, 022, 023.
Prevention	
Barriers	058, 070, 073, 074, 076, 077, 090, 126, 127.
Cover crops	002, 006, 009, 038, 042, 067, 084, 099, 114, 133.
Rotations	067,101,115.
Cultivation	008, 009, 013, 024, 026, 038, 048, 049, 051, 057, 063, 072, 096, 099, 115, 120.
Disc Implements	002, 026, 035, 044, 051, 060, 086.
Minimum-till	033, 038, 042, 049, 055, 086, 096, 101, 106, 113, 116, 124, 131.
Plowing	002, 008, 035, 055, 060, 067.
Seeders	051, 094, 096, 098, 101.
Snow traps	032, 066, 076, 090, 126, 127, 129, 133.
Straw	026, 035, 038, 044, 051, 055, 056, 059, 067, 099, 133.
Strip cropping	006, 009, 014, 022, 038, 042, 075, 084, 097, 099, 133.
Stubble	017, 026, 029, 035, 038, 044, 051, 055, 056, 061, 065, 067, 068, 088, 092, 126, 129.

Author Index