STUDIES ON

WIND PROTECTION

A DISSERTATION

SUBMITTED TO

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WAGENINGEN, THE NETHERLANDS, IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF AGRICULTURAL SCIENCES

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Dit proefschrift met stellingen van

SYED RIAZ HUSSAIN SHAH,

M. F. (Syracuse), M. F. (New York), geboren te Lahore, Pakistan, 11 november 1930, is goedgekeurd door de promotor, Dr. Ir. S. J. WELLENSIEK, hoogleraar in de tuinbouwplantenteelt.

De Rector Magnificus der Landbouwhogeschool,
W. F. EIJSVOOGEL

Wageningen, 18 september 1962

STUDIES ON

WIND PROTECTION

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD
VAN DOCTOR IN DE LANDBOUWKUNDE
OP GEZAG VAN DE RECTOR MAGNIFICUS IR. W. F. EIJSVOOGEL,
HOOGLERAAR IN DE HYDRAULICA, DE BEVLOEIING,
DE WEG- EN WATERBOUWKUNDE EN DE BOSBOUWARCHITECTUUR,
TE VERDEDIGEN TEGEN DE BEDENKINGEN
VAN EEN COMMISSIE UIT DE SENAAT
VAN DE LANDBOUWHOGESCHOOL TE WAGENINGEN
OP WOENSDAG 17 OKTOBER 1962 TE 16 UUR
DOOR

SYED RIAZ HUSSAIN SHAH

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STELLINGEN

I

Shelterbelts do not belong to the permanent farm equipment.

II

Shelterbelts increase rainfall in their protected area.

III

Mechanization does not necessarily increase the efficiency of all types of forestry operations.

IV

For increasing the use of tropical timber, advertisement and propaganda about the species should be carried out in the countries of the northern hemisphere.

V

The followers of Islam are in Europe wrongly referred to as Mohammedans.

VI

The privileged class and the common masses form 'Two Nations' in the newly developing countries; this factor has negative consequences for their development.

VII

The primary need of the newly independent states is not the development itself of new knowledge but the application of existing knowledge to their problems.

VIII

Improvement of living conditions increases productivity.

Diss. S. R. H. Shah, 1962

TO

MY BELOVED PARENTS

WHOSE LOVE, COURAGE AND PATIENCE

ENABLED ME TO COMPLETE THIS STUDY

PREFACE

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SYED RIAZ HUSSAIN SHAH

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PART TWO - SHELTERBELTS

CHAPTER I

INTRODUCTION

1 – GENERAL

High wind is the characteristic feature of the plains regions of the world. Most of the great plains of the world lack vegetation cover. Consequently this gives rise to various types of problems. Naturally, the wind erosion becomes a necessary feature of this area. The silting of irrigation and drainage canals and the increase in the rate of evaporation of soil moisture are very closely associated with the high winds character of the region. The lack of vegetation does not only add to the effectiveness of high winds in relation to wind erosion, but it also gives birth to the problems of the shortage of timber and fuelwood.

The high wind which is a principal cause involved blows away much material from some bare soils, and the wind itself becomes a dust storm. The soil material thus blown drifts across the land, forming dunes, filling up hollows, and drifting against farm buildings and hedges. The effects of wind erosion are more plainly seen in the accumulation of transported material. Wind erosion at present is principally active in desert and semi-desert regions of the world. Since only the finest particles are liable to be transported by wind, it frequently happens that a sorting out occurs whereby the fine material is removed and stones remain behind as 'desert pavement'. Modernization of agricultural practices in the arid and semi-arid regions without proper considerations could also contribute to wind erosion. For instance, the tractor which is regarded as the indicator of 'progress' could become one of the major contributors to wind erosion. The steel plowshares of the tractors have the effect of thinning out the soil and crumbling it to a fine dust, easy prey for the triumphant wind to drive it in great whirling clouds over the semi-sown and semi-desert spaces.

In addition to the lowering of the productivity of soil, however, in some parts of the world the problem of wind erosion is intensified because of the silting of irrigation and drainage canals. For instance, West Pakistan has some of the world's greatest water-diversion structures and canal systems, the dredging of these silted canals involves high expenditure. High dredging costs hinder the development activities of the country.

In many parts of the world, there is a scarcity of water. Hence the conservation of soil moisture is very important for the cultivation of land. The hot winds increase evaporation and thus reduce soil moisture.

There are many methods by which the damage caused by wind may be lessened. Shelterbelts offer an excellent method by which wind erosion and other problems related to wind damage can be solved. A shelterbelt is a wind barrier of living trees and shrubs maintained for the purpose of protecting farm fields from wind. It consists of three to twenty rows of trees and shrubs. 'Windbreak' is another term which is used. A windbreak is also a wind barrier of living trees and shrubs, maintained for the purpose of protecting the farm home, other buildings, garden, orchard or feedlots. Moreover, windbreaks are narrow strips consisting of only one or two rows of trees.

The major advantage of a shelterbelt is that it retards wind velocity which in turn brings about many beneficial results. Wind erosion and silting of canals are reduced. Soil moisture is increased. The shelterbelts also provide protection to man and livestock from cold winds of winter and hot winds of summer. Besides the above benefits, the shelterbelts also provide fuelwood and timber for the use of farmers. Thus shelterbelts not only provide one of the possible solutions to wind erosion and irrigation canal silting problems, but also provide the possible solution to the problem of fuelwood scarcity and timber shortages of the country.

West Pakistan and the other similar countries of the world are agricultural countries and their economies are dependent largely on their agricultural resources. Wind erosion is not only destroying large areas of the land, but is also reducing its productivity. Thus for the protection of these countries' agricultural resources, it is a necessity that a programme for the establishment of shelterbelts should be carried out.

In the Netherlands and some other countries of Western Europe, some farmers had cut existing shelterbelts from their farms and others have the same trend. The major reason is that the farmer could not see a direct increase in the yield of his crops. It is generally known that the shelterbelts contribute to the increase of the yield of horticultural and agricultural crops. But the farmers are doubtful about it. For protecting the shelterbelts to be destroyed by the farmers in the Netherlands and Western Europe, a research programme is needed for determining the influence of wind protection on the development and yield of crops. Furthermore, research is needed to determine the factors influenced by wind protection and responsible for the increase of crop yields. Obviously, there is need to find out the causes which destroy the anticipated increase in the yield of crops.

There are also problems relating to shelterbelt designs. Contravening theories make it very difficult to determine which is the optimum design for the establishment of shelterbelts. A research is needed which could bring forward the protective efficiencies of the different types of shelterbelts. Finally, a study is needed which could bring forward the various aspects of planning, maintenance, and administration of shelterbelts. This will result in creating more interest among the various agencies and the Governments of some countries to develop shelterbelts for the wind protection purposes.

2 – Purpose and scope of the present study

Shelterbelts have been used successfully in some regions of the world to overcome the problems caused by high winds. Thus far the most extensive shelterbelt programmes have been carried out by the United States of America and the Union of Soviet Socialist Republics. Although the advantages of the shelterbelts are known, there is dissatisfaction among farmers because of the shelterbelts disadvantages of root competition and shading, as well as decrease in the yield caused by devoting a part of the field crop area to shelterbelts. This resulted in the disfavourable attitude of the farmers for the establishment of shelterbelts.

The purpose of the present research is to present an analysis which should at least yield a guide for clearing the misconceptions of the farmers in the Western European countries, regarding the shelterbelts. The research and studies on wind protection are divided into two parts.

The first part deals with the shelter influences. The various advantages and disadvantages are reviewed with respect to wind protection. The research for determining the influence of protection from wind on the development and the yield of crops will be carried out in the fields as well as in the laboratories. A wind tunnel will also be constructed for conducting the research in a controlled environment. Experiments will be conducted seperately with the different basic factors which contribute to the higher yield of crops.

The second part deals with the shelterbelts themselves. The research will be carried out for determining the optimum design of shelterbelt for providing protection from wind. This research will be carried out by means of shelterbelt models in the wind tunnel. This study will bring forward an analysis for planning a shelterbelt project. The major phases of the shelterbelt maintenance will be discussed. Finally, an effort will be made to outline the major aspects for administrating the shelterbelt programme. The study of the literature will be limited in nature, because VAN DER LINDE and WOUDENBERG (138), and SHAH (196) have already reviewed the literature regarding the shelterbelt influences and their establishment critically.

This research will be carried out according to the climatic and topographic conditions in the Netherlands. The results from the experiments in this research could be used directly in this country. But for applying the findings from this research, in other countries, necessary modifications are needed according to the climatical, topographical, and other local conditions.

The Netherlands is situated in the temperate zone (50.5°–53.5° N) and enjoys a sea climate, that is to say it has moderate winters and cool summers, partly through the effects of the North Atlantic drift. The prevailing western and southwestern winds bring plenty of rain throughout the year. Agriculture and sea-going shipping benefit from this climate i.e. the large parts are permanently ice free. Two fifths of the Netherlands lies below sea level, rendered inhabitable only by a long established system of dunes and dikes against the perpetual attacks of the sea.

PART ONE - WIND EFFECTS AND PROTECTION

CHAPTER II

SHELTER INFLUENCES

The importance of shelter from wind should not be underestimated. It is one of the most important factors which contributes to the well-being of man, livestock and plants. The shelter could be obtained by constructing non-living artificial structures e.g. by building walls, etc. or from living structures e.g. by shelterbelts or windbreaks. The main effect of a wind barrier is that it retards wind velocity which brings about many beneficial and only a few harmful effects.

1 – ADVANTAGES OF SHELTER

The important advantages from the shelter are discussed as below:

1.1 – Retardation of wind velocity

According to studies by BATES (18), VAN DER LINDE and WOUDENBERG (138), MUNNS (159), SHAH (198), SIMS (205) and TRENK (227), the main and primary effect of a wind barrier is the retardation of the velocity of wind, which in turn produces changes in all the meteorological factors. Their studies of wind action in relation to wind barriers have shown that wind blowing directly against a living wind barrier, i.e. a shelterbelt, is diverted into one of three channels. A large part of it is deflected upwards, some of it sifts through the leaves of the trees and some passes directly under the lower branches of the trees. It has further been observed that the more flexible the trees are, the greater will be the amount of wind deflected upwards. Naturally the force of the wind which filters through the leaves of the shelterbelt trees is decidedly broken up, while that which passes under the lower branches of the trees is reduced in velocity through the friction with the surface of the ground. In consequence, on the leeward side of the shelterbelt there is a mass of more or less calm air. This air becomes disturbed by the rapidly moving current of air at the elevation of the tree tops, a disturbance that takes the form of a vertical circular of rolling motion commonly known as 'eddy' (196). The distance from the windbreak leeward in which this motion is set up is comparatively very short and also largely depends on the design of the shelterbalt itself. This may be attested by the narrow belt of snow which forms in drifts on the leeward of windbreaks.

The studies conducted by AFANSIEV (10), BATES (23), CHENEY (57), FLOYD (89), MIRONOV and SVAL'EVA (154), SNEESBY (211), TELESEC (223), WILLIAMS (249), pointed out that shelterbelts stop most of the wind erosion. One of the most harmful effects of wind erosion and one that is frequently overlooked is the removal of fine particles from the soil. The finer soil portions which result from weathering of rock particles and from decay of vegetable matter are sifted out and carried away whenever wind movement occurs. This leaves behind the coarser and heavier particles that are of the least agricultural value. When blowing is allowed to continue, the condition of soil cannot be improved since the fine particles cannot be accumulated.

1.2 – Conservation of soil moisture

The studies carried out by ASLYNG (17), BATES (23), BODROFF (36), BUDYKO and PAGOSJAN (41), CABORN (43), CARDER (50), CATRINA (51), DAUTOV (63), GLOYNE (99), GREEN (104), JENSEN (120), VAN DER LINDE and WOUDENBERG (138), LUNEZ (141), NÄGELI (162), PANFILOV (171), SIAD (188), SHIPTCHINSKY (201), SMOLIK (210), STAPLE and LEHANE (213), TAMATE (220), TODOROV and BLASKOVA (225), WOODRUFF (254) showed low evaporation under the protected area of the shelterbelt.

The evaporation of water from any wet surface and also the transpiration of moisture from the leaves of plants is accelerated by three conditions – heat, relative humidity, and rapid air circulation. Hence the shelterbelts which reduce the velocity of the air also reduce the rate of evaporation. This results in an appreciable saving of the moisture supply. Thus it is the source of greatest benefit since in the region where shelterbelts find their greatest usefulness, moisture is almost always insufficient for the best interests of agriculture.

Shelterbelts may be built up as screens around dams and canals to prevent silting and to maintain water volume.

1.3 – Increasing crop yields

BATES (24), VAN RHEE (182), RANGE and ODELL (186), STEWART (215), ZON (262) showed that shelterbelts increase the output of crops. For example, the yield of wheat in the prairie region increased as much as 10 to 20%, cotton fiber yields increased 12% and the yield of forage crops increased by 36%. VAN RHEE'S (182) experiments showed 45% and 162% increase in the yield of apples and pears respectively under the protection of the windbreak. CHEYNEY (57) reported that the growth of a large number of trees was also accelerated, especially in height, due to retardation in wind velocity. The existing experiments on the increase of crop yields under the protection of the shelterbelts gave no clear clarification, that how and why the increase in crop yields took place, consequently the doubts of the farmers regarding the shelterbelts came in.

1.4 – Increase of fertility of saline soils

ZEMLSANICKIJ (259) concluded from his experiments that the shelterbelts increase the fertility of saline soils. The fallen leaves, branches, etc. played an important part in improving the soil conditions. The leaves and branches mineralize over a period of time to give calcium which deplaces sodium. The other important factor is snow which accumulates in and around shelterbelts. This snow melts and leaches the soluble salts to the deeper layers of the soil. The author will like to add that the shelterbelts reduce the rate of free evaporation and of transpiration which results in a lower rate of the capillary action and hence the accumulation of soluble salts in the soil surface is reduced. All the above factors acting together may increase the fertility of saline soils.

1.5 – Protection to man and livestock

BATES (18) and FLOYD (89) reported that shelterbelts provide protection to man and the home from cold winds of winter. Similarly they provide protection in summer from hot winds. The home is cooler in summer and less expensive to heat in winter. Heating requirements of the house will be reduced due to modified wind velocities.

Those animals that can enjoy fresh air in the protection of a good windbreak are in far better condition in the spring than those which have been cooped up in a stable all winter or exposed to the cold winds when they go outside (159). Livestock may be fattened and maintained more economically than when fed in unprotected feed yards. For example, the studies have shown that cattle wintered on the same ration gains more in a normal winter in tree-protected feeding grounds than in unprotected areas (87). Sheep losses during early lamb season will be reduced if the animals are protected from cold winds. Shelterbelts protect feeding areas from drifting snow. Also cattle wintered in tree-protected areas loses less weight during severe blizzards than those wintered in exposed locations. The farmer who has not extended his windbreak to his barns and paddocks has missed one of the best paying phases of windbreak protection.

1.6 – Furnish fullwood, timber and recreation

Shelterbelts also supply fuelwood and fence posts for the farm. Williams (247) and Munns (159) pointed out the aesthetic and recreational value of shelterbelts. Shelterbelts increase the beauty of the landscape. An aesthetic value increases the pride of the farmers. The shelterbelts are a potential recreational area for the farm family, particularly for the children.

2 – Disadvantages of shelter

Here a word must be said about the disadvantages which may result especially from the living wind barriers, such as shelterbelts, although much can be done to minimize these drawbacks.

2.1 – Reduction of the effective agricultural acreage

The use of land for building a wind barrier reduces the effective agricultural acreage. This applies more to land under crops, however, than to open land.

2.2 – Competition between the trees of the living wind barrier and the adjoining crop

Bates (22) and Cadman (47) reported that there is competition for light, moisture and soil nutrients between the trees of the living wind barriers and the adjoining crops.

2.3 – Shading

Shading of the wind barriers on the adjoining crops is another adverse factor. This may cause lateness in spring and reduce quality and quantity of the crop for a narrow zone adjoining the shelterbelt. Some crops suffer more than others.

2.4 – The incidence of frost

Lower night temperatures and calm conditions in the protected area may result in some increase of the incidence of frost.

2.5 – Less possibility of drying in a wet period

Shah (199) found in his experiments that the windbreaks decrease the possibilities for drying in a wet period which resulted in the accumulation of excessive moisture in great amount, consequently the plant diseases invaded and damaged the yield of crops. The author adds that each crop behaves in a different way to the accumulation of moisture. In certain crops the damage is high, in others low and some have practically no damage.

2.6 – Obstruction of mechanized farming

The wind barriers may cause obstruction to mechanized farming.

3 – Conclusions

There is no doubt that the benefits from the protection of wind by means of living wind barriers outweigh the few detrimental effects. But the studies on shelter effects lack the facts about the details of behaviour of plants under the protection of wind barriers. Especially no information is available how the crop responds to the wind protection at the various stages of its life cycle. The major factors responding to wind protection which are responsible for the increase of the crop yields are still to be uncovered. In the next chapter, the author will bring forward the conclusions from his research how bean and maize crops behaved during their life cycles under the wind protection.

CHAPTER III

THE INFLUENCE OF THE ARTIFICIAL WINDBREAK ON THE DEVELOPMENT AND YIELD OF BEAN AND MAIZE CROPS IN THE FIELD

For determining the influence of the artifical windbreak under field conditions on the development and yield of bean and maize crops, the author conducted experiments in eleven fields in various parts of the Netherlands during the 1960 and 1961 growing seasons. The reason for carrying out so many field experiments in a number of places was due to the local climatic conditions which are quite different from one part to another. The great number of field experiments provided the opportunity to compare the results and also provided data which could be directly applied to the various microclimates in the Netherlands. The experiments were repeated in 1961 for checking the results of the previous year. The analyses of the results in all the experiments were almost similar. Therefore, the author selected two representative experimental fields of bean and maize crops respectively for discussing in detail. But all the original results of all experimental fields are given as appendices in microfilm which can be found at the end of this publication in the pocket. Table 1 summarizes the results of the increase in yields of bean and maize crops in eleven experimental fields.

Table 1 – THE SUMMARIZED RESULTS OF THE INCREASE IN YIELDS OF BEAN AND MAIZE CROPS AT THE ELEVEN EXPERIMENTAL FIELDS UNDER THE PROTECTION OF THE ARTIFICIAL WINDBREAK

Experimental Field	Location	Year	Crop	Increase in yield (expressed in %)
RD.	RANDWIJK (Gelderland)	1960	Bean	4****
RL.	RANDWIJK (Gelderland)	1960	Bean	17**
G.	GOES (Zeeland)	1960	Bean	12***
B.	BRUINISSE (Zeeland)	1960	Bean	2**
E.	ELST (Gelderland)	1961	Bean	18**
GG.	GOES (Zeeland)	1961	Bean	7**
BB.	BRUINISSE (Zeeland)	1961	Bean	0***
K.	KAPELLE (Zeeland)	1960	Maize	10**
S.	KAPELLE (Zeeland)	1960	Maize	17***
R.+	SPRUNDEL (Noord-Brabant)	1960	Maize	0***
T.	LUNTEREN (Gelderland)	1960	Maize	10***

* Significant at 10% level
** Significant at 5% level
*** Significant at 1% level
**** Not significant
\+ This field had negative fertility

1 – THE EXPERIMENTAL AREA AND THE MICROCLIMATE

Both experimental fields were located in the province of Zeeland at Goes and Kapelle respectively, see fig. 1.

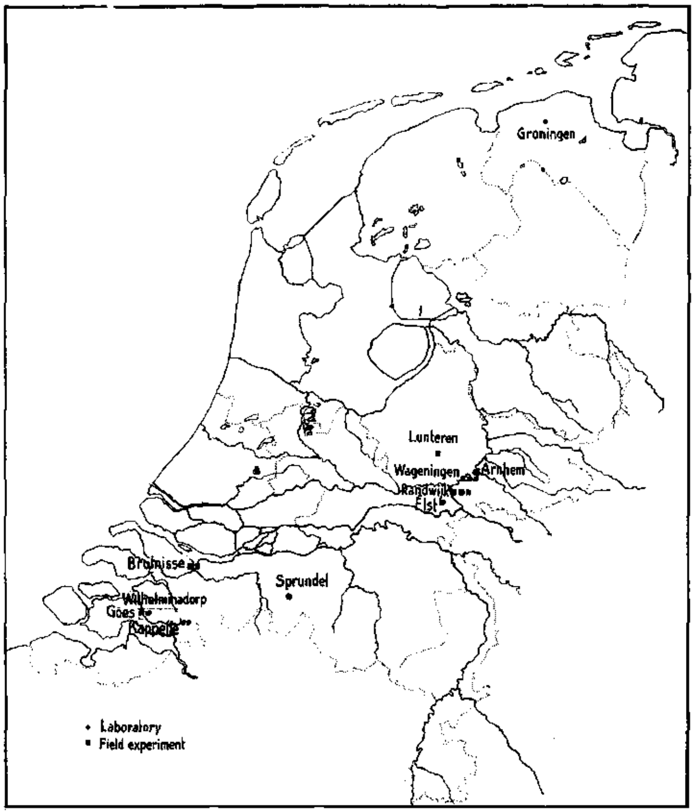

Fig. 1. Map of the Netherlands showing the location of the field experiments and the laboratories where the research was conducted.

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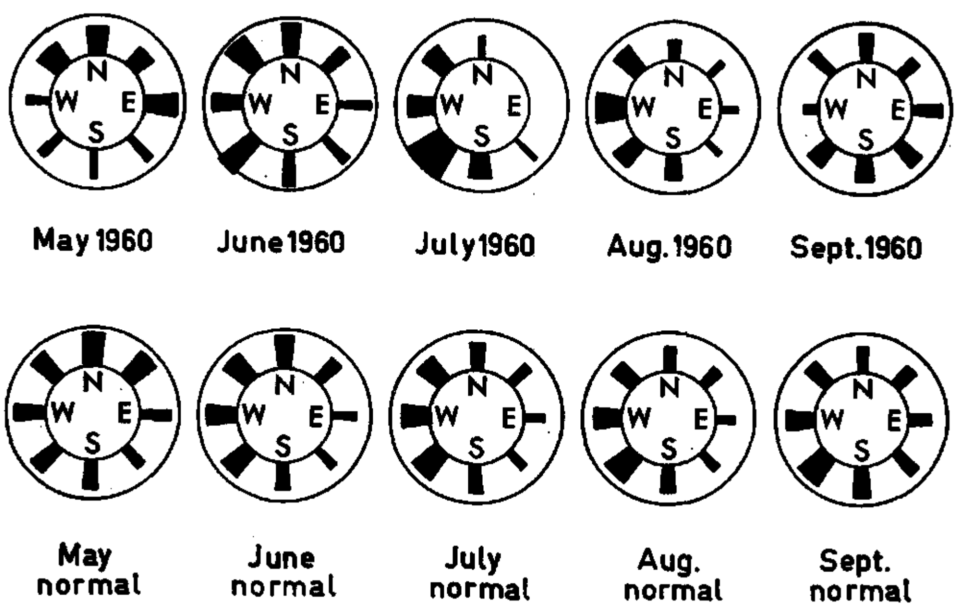


Fig. 2. Winds during the growing season of 1960 in Zeeland. Their procentual distribution is indicated by the width of marks, and their medium velocity by the lenght (up to outer rim of compass-cards = 5 m/sec). Source: Shah (199).

V

The rainfall in Zeeland is given in Table 2 for the growing season of 1960. This rainfall was abnormally high for the last part of the growing season in 1960. The temperatures for the growing season in Zeeland during the growing season of 1960 are given in Table 3. The wind conditions in Zeeland for the growing season of 1960 are given in Table 4 and described in fig. 2 respectively.

Table 2 – RAINFALL IN ZEELAND DURING THE GROWING SEASON OF 1960
SOURCE: ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE AT DE BILT

Month	Time period	Total quantity of rainfall mm	Number of hours rainfall	Thunder and lightning in days
May	First 10 days	1	1	—
	Second 10 days	29	17	1
	Last 11 days	28	15	—
	Total of month	57	33	1
	Av. of last 30 years	49	—	4
June	First 10 days	10	11	—
	Second 10 days	13	4	1
	Last 10 days	6	4	—
	Total of month	29	19	1
	Av. of last 30 years	52	—	5
July	First 10 days	24	21	—
	Second 10 days	21	7	—
	Last 11 days	36	22	3
	Total of month	81	50	3
	Av. of last 30 years	66	—	4
Aug.	First 10 days	15	15	1
	Second 10 days	66	28	—
	Last 11 days	44	10	—
	Total of month	125	53	1
	Av. of last 30 years	63	—	5
Sept.	First 10 days	38	10	—
	Second 10 days	17	27	—
	Last 10 days	59	27	—
	Total of month	114	64	—
	Av. of last 30 years	74	—	3

Table 3 – TEMPERATURES (IN °C) IN ZEELAND DURING THE GROWING SEASON OF 1960
SOURCE: SHAH (199)

Month	Time period	Average 24 hours	Average daytime	Average daily max.	Average daily min.
May	First 10 days	12.5	14.1	17.4	8.1
	Second 10 days	13.6	14.2	17.2	10.9
	Last 11 days	12.8	13.6	15.6	10.6
	Av. of month	13.0	14.0	16.7	9.9
	Av. of last 30 years	12.0	13.0	15.9	8.9
June	First 10 days	16.3	17.5	20.5	12.8
	Second 10 days	15.6	16.7	19.3	12.7
	Last 10 days	15.8	16.7	19.4	13.4
	Av. of month	15.9	17.0	19.7	12.9
	Av. of last 30 years	15.0	16.1	18.7	12.0
July	First 10 days	15.2	16.0	17.8	13.0
	Second 10 days	16.1	17.2	18.9	13.7
	Last 11 days	16.4	17.2	18.9	14.3
	Av. of month	15.9	16.8	18.5	13.7
	Av. of last 30 years	17.2	18.2	20.9	14.3
Aug.	First 10 days	17.0	18.0	20.6	13.9
	Second 10 days	15.5	16.1	18.3	13.2
	Last 11 days	17.6	18.3	20.7	15.6
	Av. of month	16.7	17.5	19.9	14.3
	Av. of last 30 years	17.3	18.2	20.8	14.4
Sept.	First 10 days	15.5	15.9	18.1	13.5
	Second 10 days	16.2	16.9	19.6	14.0
	Last 10 days	12.8	13.3	15.7	10.1
	Av. of month	14.8	15.4	17.8	12.6
	Av. of last 30 years	15.3	15.9	18.5	12.8

Table 4 – WIND CONDITIONS IN ZEELAND DURING THE GROWING SEASON OF 1960
SOURCE: SHAH (199)

Month	Time period	North		North-east		East		South		South-east		South-west		West		North-west		No wind
		%	V	%	V	%	V	%	V	%	V	%	V	%	V	%	V	%
May	First 10 days	23	4	23	4	16	5	4	5	4	3	3	3	11	4	10	3	7
	Second 10 days	20	4	30	4	20	6	5	4	4	3	3	3	11	4	7	3	–
	Last 11 days	34	5	12	4	2	3	5	3	4	3	8	4	12	5	14	4	6
	Av. of month	25	4	21	4	12	5	5	4	6	3	5	3	11	4	10	4	5
	Av. of last 30 years	17	4	17	5	11	4	6	3	9	5	14	5	16	5	10	4	1

Month	Time period	North		North-east		East		South		South-west		South-		West		North-west		No wind
		%	V	%	V	%	V	%	V	%	V	%	V	%	V	%	V	%
June	First 10 days	12	5	15	4	17	4	6	4	8	7	19	9	20	7	3	5	–
	Second 10 days	13	6	2	5	1	3	1	2	7	5	39	8	31	7	4	3	0
	Last 10 days	33	6	10	4	9	5	3	3	–	–	1	6	14	6	32	6	0
	Av. of month	19	6	9	5	9	5	3	4	5	6	20	8	22	7	13	6	0
	Av. of last 30 years	14	4	11	4	7	3	4	3	7	5	16	6	26	6	15	4	1
July	First 10 days	6	5	–	–	–	–	5	5	11	5	35	9	20	7	23	5	–
	Second 10 days	3	5	–	–	–	–	3	6	18	8	49	8	25	7	3	5	–
	Last 11 days	6	3	4	2	1	2	–	–	6	6	31	6	37	6	14	4	2
	Av. of month	5	4	1	2	0	2	2	5	11	7	38	8	28	6	13	4	1
	Av. of last 30 years	9	3	9	3	7	3	5	3	10	5	20	6	28	6	13	4	0
Aug.	First 10 days	18	4	10	3	3	3	2	3	5	5	26	5	18	5	18	3	1
	Second 10 days	11	5	13	3	4	3	4	4	8	5	27	7	20	7	12	6	–
	Last 11 days	2	2	3	3	6	3	10	4	15	5	26	7	26	7	9	5	2
	Av. of month	10	4	8	3	4	3	5	4	9	5	22	7	22	7	13	4	1
	Av. of last 30 years	10	3	9	4	8	3	5	3	11	5	24	6	24	6	11	4	1
Sept.	First 10 days	8	3	4	2	3	3	3	3	8	4	33	7	18	6	18	4	6
	Second 10 days	10	4	8	4	20	5	24	5	10	5	5	5	3	9	6	8	0
	Last 10 days	12	3	27	4	27	6	4	5	9	5	8	5	5	10	7	10	1
	Av. of month	10	4	13	4	16	5	12	5	12	5	15	6	9	7	10	6	–
	Av. of last 30 years	9	3	11	3	10	3	6	3	16	6	18	6	19	6	10	4	2

% = Number of hours in percentages
V = Average velocity in m/sec

2 – Methodology

The experimental field for the bean crop was located outside Goes, and for the maize crop outside Kapelle. The concerning bean crop field was acquired in the Agricultural Experiment Farm at that place and was used to a width of 12 m and length of 90 m. The concerning maize field was used to the breadth of 6 m. The orientation of both fields was such as to face approximately the winds coming from southwest. The topography was flat. The soil of both fields was clay and had a good fertility, which was fairly distributed.

For the protection from the southwesterly winds, the author designed a special artificial windbreak which in principle was in complete agreement with the Usman type shelterbelt model, except in air drainage. (The details are described in Chapter VII, p. 69). The present windbreak consisted of vertical strips of colourless plastic in wooden frames and was designed in such a way as to keep 33% air drainage through it. See fig. 3.

There are a few great advantages for using artificial windbreaks for experimental research work:

A. It gives the research worker a chance to find his experimental field in open area and according to his crop requirements.
B. There is no shading effect as in case of a natural windbreak on the adjoining strip of the field crop.
C. There is neither competition for the soil nutrients and light etc., between trees and the adjoining strip of the crop.

The artificial windbreak was fixed in the field so as to divide it into two sections:

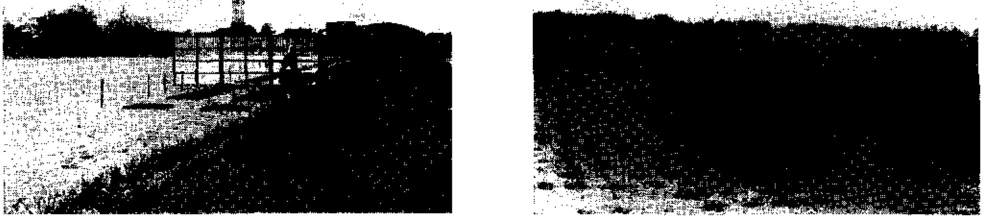
Fig. 3. One of the experimental fields of bean crop. This field was located at Randwijk. The artificial windbreak can also be seen.

a. In front of the windbreak an area which was unprotected and open for the south-westerly winds;

b. In the leeward side an area which to varying degrees was protected from them.

The artificial windbreak used in the maize crop experimental field was similar to the windbreak used in the bean crop experimental fields, except in height. The height of the artificial windbreak used in the maize field was 2 m. The artificial windbreak used for the maize crop experimental field can be seen in fig. 4.

The original results of the field experiments are given as the appendices in the end of this publication. The lines on the graph paper presenting the results run into each other, consequently they present difficulty in understanding for the reader. An example is



Before crop After crop

Fig. 4. The artifical windbreak in the experimental field of maize crop at Kapelle.

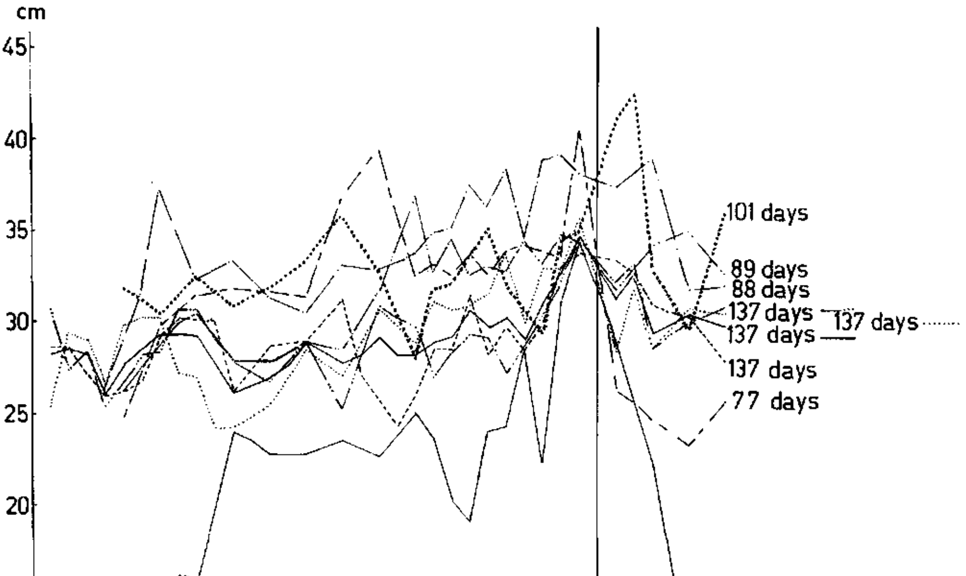


Fig. 5. The development of the height of bean crop under the protection of the artificial windbreak at Goes (Zeeland). This graph has been prepared with the original results, not with the computed averages.

provided in fig. 5, where the graph lines represent the development of the height of bean crop under the protection of the windbreak at Goes (Zeeland).

For making the lines on the graphs smoother and easier to read, the author followed a special system on the recommendation of the statisticians of the Agricultural University at Wageningen. The values at 1 H_l and 1 H_W were left as original ones. But the average results were computed for 2 H_l till 10 H_l, 12 H_l till 20 H_l, 22 H_l till 26 H_l, and 2 H_W till 5 H_W respectively. From these six points the curves of the various results were developed. Statistical analysis was also carried out for determining the significance of the results.

3 – The analysis of the development and yield of bean crop under the influence of the windbreak

The bean crop *(Phaseolus vulgaris*, variety N-1507) was sown on May 2, 1960. A couple of days after the crop was sown, the artificial windbreak was fixed. The experimental field was weeded out regularly. A good watch was kept if any external of abnormal factors were interfering with the growth of plants. Regular visits were made to check the behaviour and development of the plants.

When the plants gave their first appearance, the author started his proper observations i.e. the growth analysis. The total numbers of leaves, inflorescences, buds, flowers, pods, seeds, nodes, the total height of the plant to the last node, and the wet and dry weights of the plants were determined. The sampling comprised 50 different plots of 15 plants each, viz. 40 in the leeward and 10 in the windward side of the windbreak. According to their place in respect of the windbreak, they were indicated as 1 H_l, 2 H_l, 3 H_l, 4 H_l, 5 H_l till 40 H_l (leeward) and 1 H_W, 2 H_W, 3 H_W till 10 H_W (windward). Each 'H_l' and 'H_W' corresponds to the height of the artificial windbreak i.e. 1 m. In total the author carried out seven samplings for the purpose of growth analysis when the plants were 28, 42, 54, 77, 88, 98, and 113 days old respectively. The yield determination was carried out when the plants were 137 days old.

Discussion of results. In the first place by visual examination, the author observed better growth and development of the plants in the protected zone than in the zone which was open to the winds. The results of the growth analysis are expressed in figures 6 and 7 respectively.

The author points out that in the following discussions the protected zone will be considered only up to 10 H_l. The reason for limiting this zone up to 10 H_l is due to the fact that the protection provided by the windbreak was maximal up to 10 H_l and from 10 H_l to 20 H_l decreased.

The details of some salient features regarding the influence of wind protection expressed as the percentage increase in the protected zone as compared with the non-protected zone is given in Table 5.

The results clearly indicate that the effect of wind protection on the growth of plants was apparent, even in its early stages of growth e.g. the height of the plants was 44% higher in the protected zone at the age of 28 days. The lead in the growth of bean plants was maintained up to the age of 88 days. But at the age of 113 days, the influence of the wind protection started declining unexpectedly. Later when the final growth analysis of bean crop was carried out at the age 137 days, there were no significant differences in wet and dry weights as well as in the heights between the plants of the protected and non-protected zones.

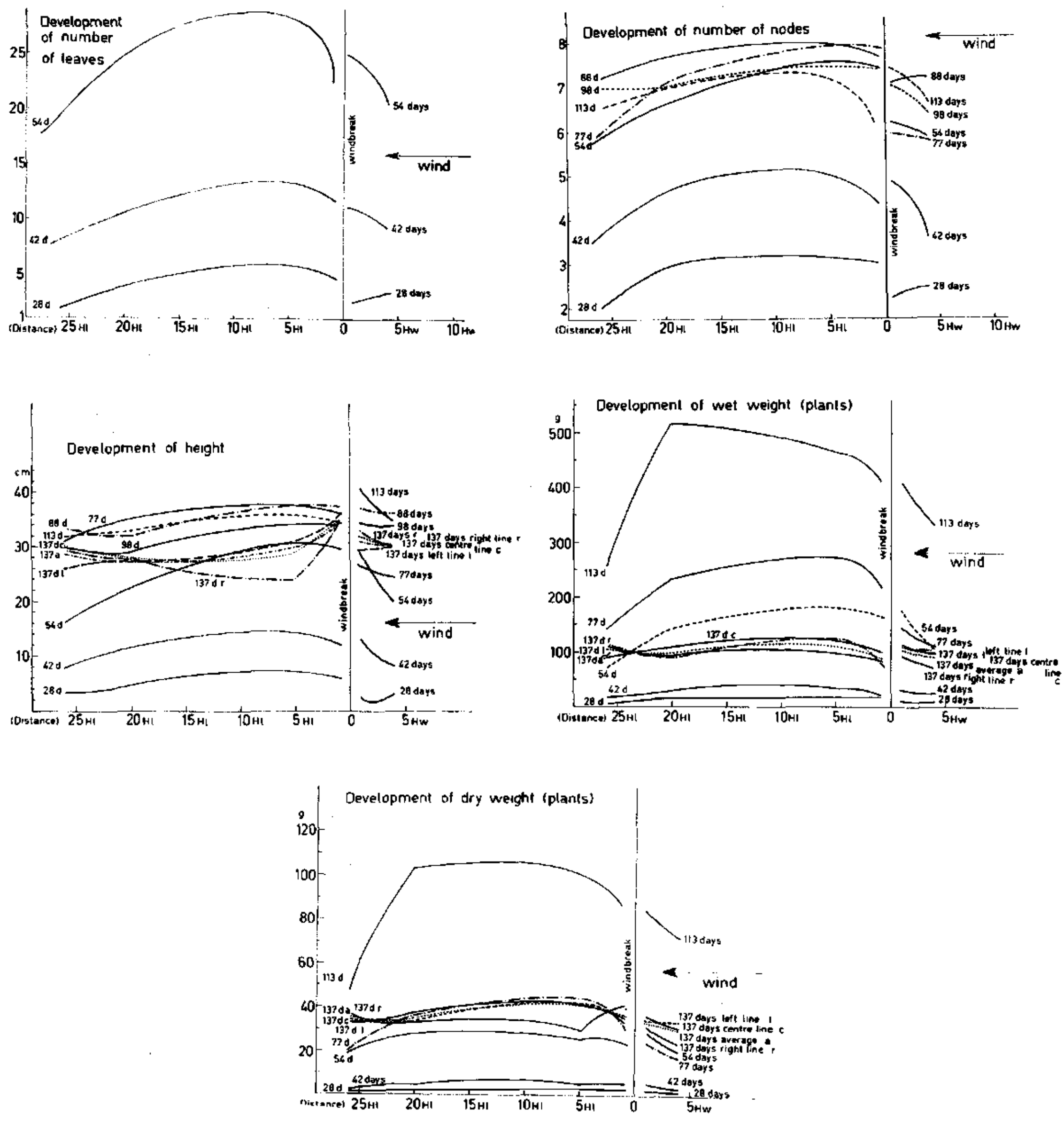


Fig. 6. The development and growth of the bean crop under the influence of the windbreak in the field G at Goes.

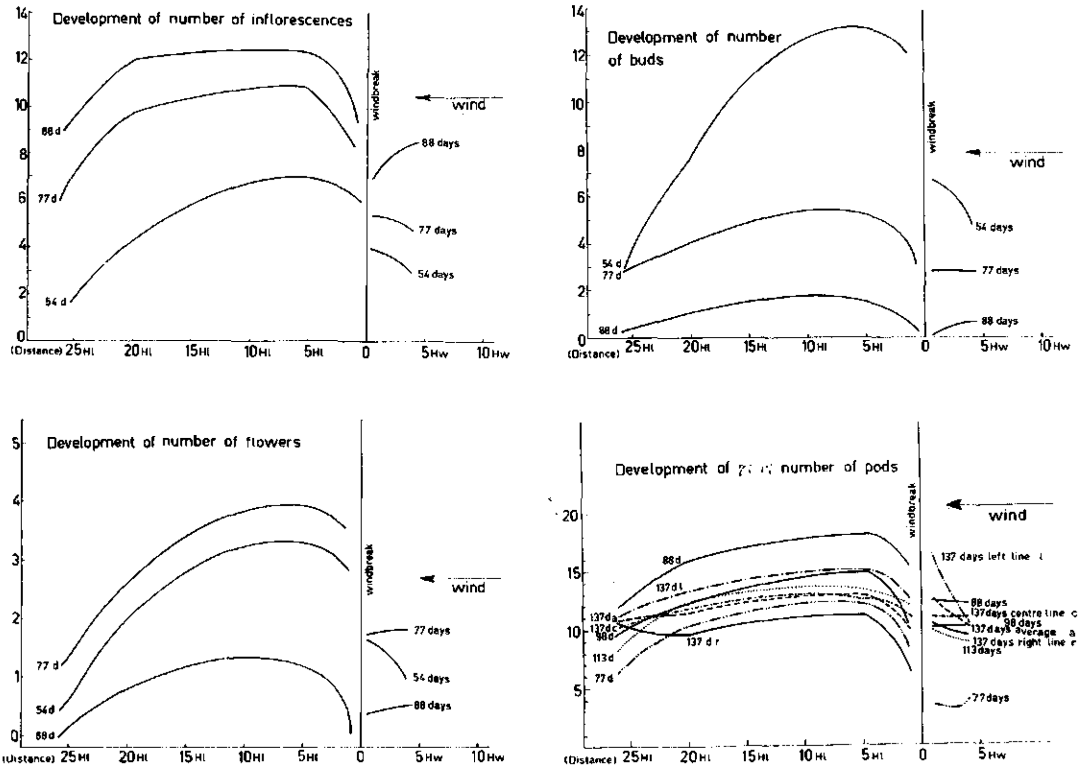


Fig. 7. The flowering of bean crop under the influence of the windbreak in the field G at Goes.

The author will like to add that during his various analyses he noticed that the leaves of the plants in the protected zone started falling earlier as compared with the plants in the non-protected zone, during the later ages of the plants. This had also an effect on the wet and dry weights. Another striking observation was the earlier flowering in the protected zone.

The results of the yield determination are described in fig. 8.

Three lines of sampling plots were reserved from the beginning of the experiment for the purpose of the yield analysis. These three lines were running through the centre, the left and the right sides of the field respectively. The yield of bean seeds was 12% higher in the protected zone as compared to the non-protected zone. The yield of high quality seeds was only 10% higher in the protected zone.

The promising surplus in the growth of the plants and the corresponding anticipated high yield of the crop in the protected zone underwent a sudden decline in August. The moment in which the obviously positive influence of the windbreak started to decrease corresponded with the beginning of a period of abnormal and excessive rainfall, in the months of August and September. In a region suffering from very high rainfall, as was the case in August and September, 1960, a negative influence on the yield may be expected from wind protection if in the same period the windbreak was

Table 5 – SOME SALIENT FEATURES REGARDING THE EFFECT OF WIND PROTECTION EXPRESSED AS THE PERCENTAGE INCREASE IN THE PROTECTED ZONE IN THE EXPERIMENTAL FIELD WITH BEAN CROP AT GOES IN 1960

Age (in days)	28	42	54	77	88	98	113	137
Number of nodes . . .	19			27***				
Height of plants . . .	44***	34***	23	24***				
Wet weight plants . .			29	60			27	
Dry weight plants . .			30***	59***			22***	
Number of leaves . . .	25	25	26**	20				
Number of inflorescences			55	43	53			
Number of flowers . .			65	53				
Number of pods . . .				67***	33	31	27	18***
Dry weight pods . . .								19***
Number of seeds . . .								22
Dry weight seeds . . .								12*
High quality seeds . .								10

* Significant at 10% level
** Significant at 5% level
*** Significant at 1% level
No star(s) = Untested

effective indeed. Then, as a matter of fact, the wind reduction is detrimental because it retards the evaporation. Probably by the accumulation of excessive moisture, different plant diseases develop and the plants under the wind protection start rotting.

Even the abnormal high rainfall destroyed the anticipated high yield of the crop in the protected zone, but still the yield was 12% higher in the protected zone as compared with the non-protected zone. This clearly indicates that under the normal microclimatical conditions of Zeeland the windbreak would have played a very significant role in increasing yields in the protected zone.

Conclusions. The plants of bean crop in the protected zone were leading in growth rate over the plants in the unprotected zone to a considerable extent. But due to abnormal unfavourable weather conditions the lead in the growth of bean crop in the wind protected zone was lost. Consequently, the increased yield of bean crop in the wind protected zone was only 12%. Under the normal weather of Zeeland, the yield would have been much higher than the present results.

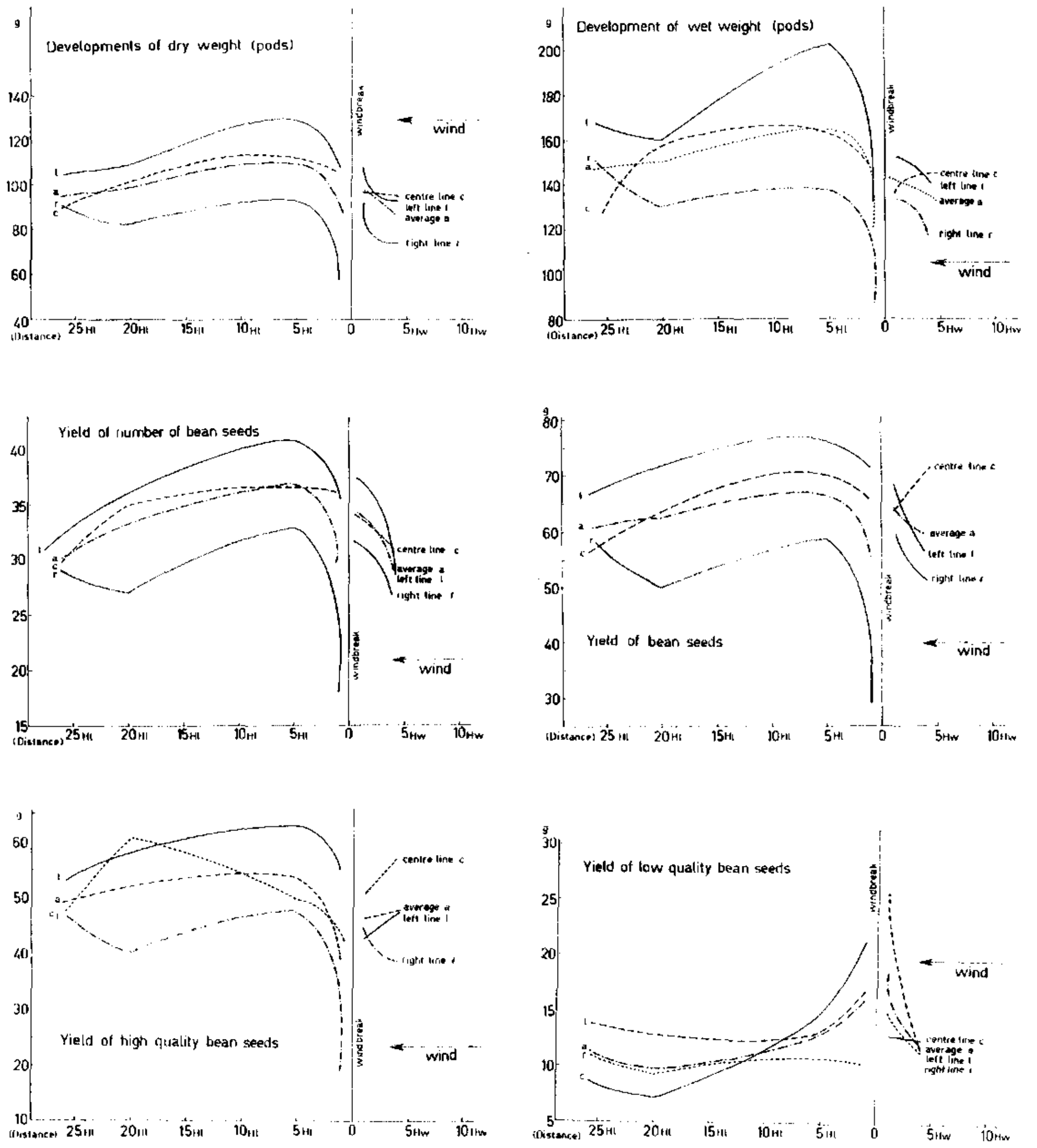


Fig. 8. The yield analysis of bean crop 137 days old under the influence of windbreak in the experiment field G at Goes.

4 – The analysis of the development and yield of maize crop under the influence of the windbreak

The maize crop (variety Pioneer X 6132) was sown on April 27, 1960. Five days later the windbreak was fixed. Weeding was carried out in the experimental field regularly. Good control was kept if any external or abnormal factors were interfering with the growth of the plants. Regular visits were made to check the behaviour and development of the plants in the protected and non-protected zones.

The author started his growth analysis as soon as the seeds germinated. The total number of leaves and of nodes, the height of the plants to the last node, the wet and dry weights of plants in the sampling plots, the wet and dry weight of the cobs and the dry weight of the kernels were determined. The sampling comprised 50 different plots of 10 plants each, viz. 40 in the leeward side and 10 in the windward side of the windbreak. According to their place in respect to the windbreak, they were named as 1 H_l, 2 H_l, 3 H_l, 4 H_l, 5 H_l, till 40 H_l (leeward), and 1 H_w, 2 H_w, 3 H_w till 10 H_w (windward). Each 'H_l' and 'H_w' denotes the height of the windbreak i.e. 2 m. Six samplings were carried out for growth analysis when the plants were 30, 56, 80, 90, 103 and 124 days old respectively. The yield determination of the maize crop was conducted when the plants were 173 days old.

Discussion of results. The growth and development of maize crop were better in the protected zone as compared with the crop in the non-protected zone. In this case, the protected zone where the influence of the windbreak was optimal is up to 5 H_l. The reason for the relatively small length of the protected area was due to the very narrow breadth of the windbreak i.e. 6 m (= 3 H_l). But still some favourable influence can be seen up to the distance of 20 H_l. The results of the growth and development analysis of maize crop is expressed in fig. 9.

The results of the various analyses indicate clearly that the rate of growth was superior up to the maize crop age of 90 days, in the protected zone of the windbreak. For instance, the height and dry weight of maize plants were higher 36% and 29% respectively when the maize crop was 90 days old. Table 6 gives the influence of wind protection on some characters of maize crop.

Table 6 also shows that the influence of wind protection declined considerably when the maize crop reached the age of 103 days. The major reason for the decline in influence of the wind protection on the growth of maize crop may be attributed to the height of the artificial windbreak which was rather small i.e. only 2 m. When the plants were 103 days old, they were as high as the artificial windbreak. Consequently, the windbreak was practically providing no wind protection any longer to maize plants.

The yield determination was carried out when the maize crop was 173 days old. The results are given in fig. 10. The wet and dry weights of cobs were about 19% higher in the protected zone as compared with the non-protected zone. The yield of kernels was 17% higher and the high quality kernels were 18% higher in the protected zone.

Conclusions. The growth analysis clearly showed that the growth of maize crop was better in the protected zone, till the age of 103 days. After the age of 103 days, the growth analysis and the final development analysis never showed any significant difference between the maize plants growing in the protected and non-protected zones. The yield determination showed an increase of 17% crop yield in the protected zone as compared with the non-protected zone.

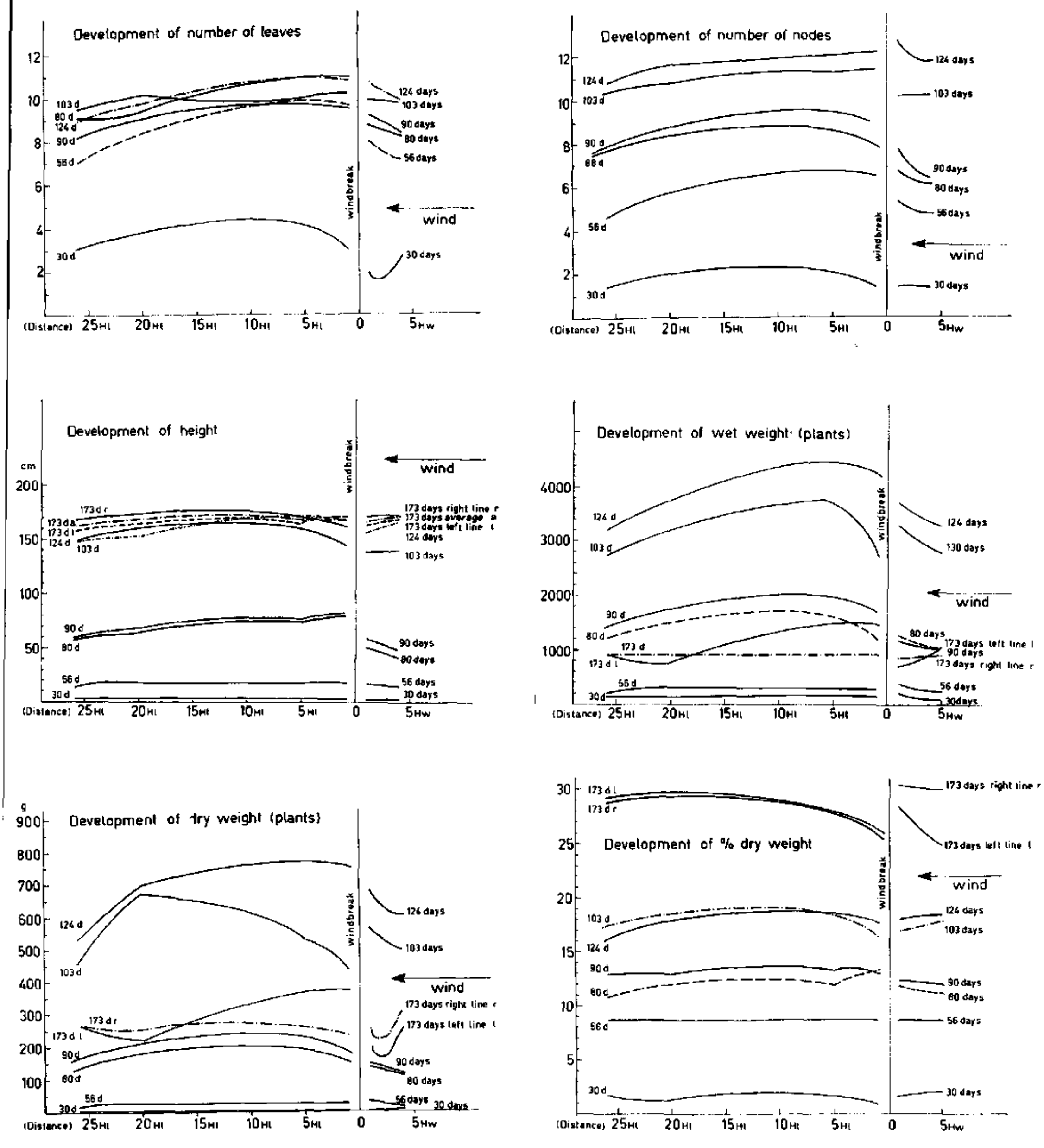


Fig. 9. The development and growth of maize crop under the influence of the windbreak in the field S at Kapelle.

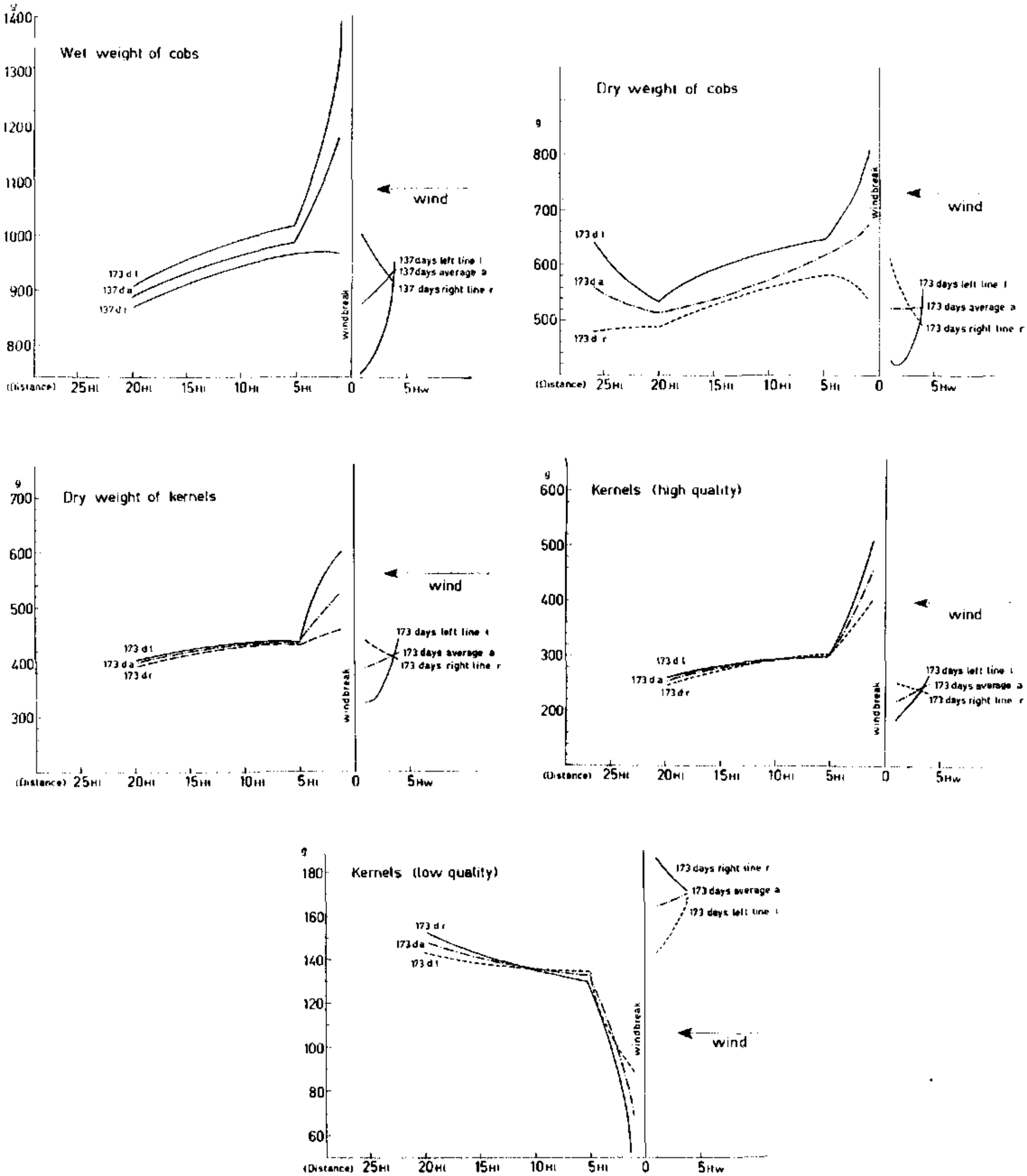


Fig. 10. The yield analysis of maize crop under the influence of the windbreak in the field S at Kapelle.

Table 6 – SOME SALIENT FEATURES REGARDING THE EFFECT OF WIND PROTECTION EXPRESSED AS THE PERCENTAGE INCREASE IN THE PROTECTED ZONE IN THE EXPERIMENTAL FIELD WITH MAIZE CROP AT KAPELLE IN 1960

Age (in days)	30	56	80	90	103	124	173
Number of nodes	22	26	29	34	9		
Height of plants	14*	18**	46	36	12***		
Dry weight plants			39***	29	12	12	9
Number of leaves	31	22***	22	22***			
Dry weight cobs							19***
Dry weight kernels							17***
High quality kernels							18

* Significant at 10% level
** Significant at 5% level
*** Significant at 1% level
No star(s) = Untested

5 – FINAL CONCLUSIONS

The research in the bean and maize field experiments brought forward the following facts:

a. The general trend of the earlier growth and development of bean and maize crops in the field experiments was similar. The difference in the trend between beans and maize appeared as soon as the abnormal rainfall started during the last part of the growing season.

b. The limiting factors in determining the size of the protected zone for any crop are the length and the height of the windbreaks. For providing optimal protection to the agricultural crops, it is desirable to make the windbreak much broader than the field to be protected.

c. The excessive rainfall was responsible for reducing the promising surplus to a very poor increase of the yield of 12% in bean crop in the protected zone of the windbreak. The high rainfall turned the wind protection into a negative influence on the yield. Under these circumstances, the reduction in the wind velocity is detrimental, because it retards evaporation. It may be due to the accumulation of moisture that different plant diseases develop and the plants in the protected zone start rotting, ultimately causing the poor yield of the crop.

d. Before establishing shelterbelts or windbreaks especially for increasing the yield of crops such as bean crop, it is important to be cautious in the regions with an extremely wet climate.

e. The maize crop even under the protection of a small windbreak, i.e. 2 m in height and 6 m in length was able to increase the yield by 17% in the protected zone as compared with the yield in the non-protected zone. The growth and yield of the maize crop would have been much better under the protection of a good type of windbreak, with reasonable height and length.

In the next chapter the author will bring forward the results from the experiments which he conducted in the wind tunnel under the controlled environment with respect to wind velocity and protection.

Chapter IV

THE INFLUENCE OF THE ARTIFICIAL WINDBREAK ON THE DEVELOPMENT AND YIELD OF BEAN AND MAIZE CROPS IN THE LABORATORY

For determining the influence of the shelterbelt on the development and yield of agricultural crops in the laboratory, the author designed and constructed a wind tunnel (the first of its kind in the world) in which such research was possible. Crops could be grown in the wind tunnel closely to the field conditions. Moreover, the author designed the artificial windbreak. The same type of artificial windbreak was used in the wind tunnel as in the field experiments. Consequently, the research in the laboratory could provide the answers to many of the problems in the field experiments.

1 – Methods

1.1 – Wind tunnel description. The wind tunnel was constructed in the laboratory of the Department of Horticulture, State Agricultural University at Wageningen. It was situated in a hot glasshouse, and therefore could be operated during most parts of the year. The wind tunnel was made on the principle of internal circulation of the air. Both ends were open in the glasshouse. At the one end three fans (68/14 D type) were fixed. These three fans were run by an electric motor of 1.5 horse power. One more electric motor of 0.5 horse power was added, so that the other motor could stop for some time for cooling down. There were eight blades on each fan. The diameter of each fan was 68 cm. Each fan forced 20,000 cubic metres of air per hour constantly. Also each fan

Fig. 11. The three fans which are run by an electric motor in the wind tunnel can be seen in this plate. Also the starter of the electric motor and the speed controller are visible.

Fig. 12. Closer view of the three fans and the electric motor which operates them.

gave 200 to 1200 revolutions per minute varying according to eight different speeds. The three fans and the electric motor in the wind tunnel can be seen in fig. 11.

The closer view of the three fans and the electric motor which operates them is given in fig. 12.

The total length of the wind tunnel was 25 m, but its effective length was 17.50 m. The whole length of the wind tunnel was covered with strong colourless plastic. The plastic was supported by eleven iron bars which were joined on the top with one long iron and also were connected with two times three iron bars throughout the length of the wind tunnel on left and right sides respectively. The closer view of the iron bars which support the plastic of the wind tunnel can be seen in fig. 13. The complete view of the wind tunnel covered with plastic and supported by iron bars can be seen in fig. 14. The eleven iron bars were placed at 2.5 m apart from each other. The width of the wind tunnel was 1.58 m and the height was 2.00 m. Further details of the wind tunnel are given in the diagram presented in fig. 15.

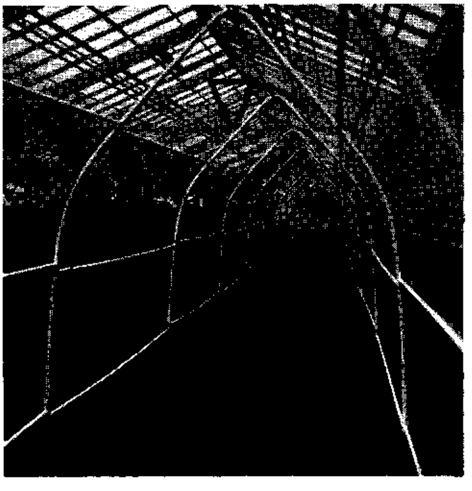


Fig. 13. Closer view of the iron bars which are to support the plastic of the wind tunnel.

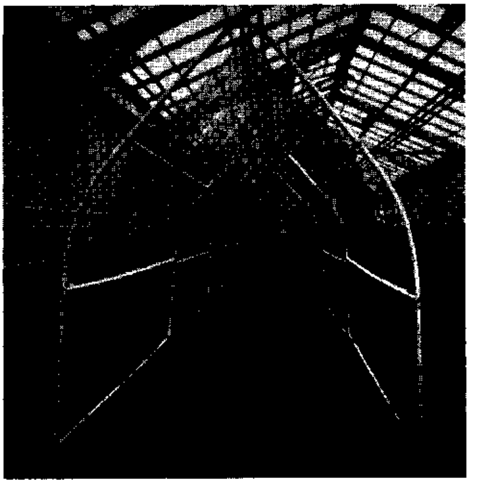


Fig. 14. The complete view of the wind tunnel which is covered with plastic and supported by iron bars. In the distance three fans can be seen which create wind in the tunnel. From the roof of the wind tunnel is hanging the pipe which creates the rain irrigation system.

A windscreen (Usman type, shelterbelt model to be discussed in Chapter VII) acting as an artificial windbreak was fixed in the soil at the distance of 17 m from the rear end of the wind tunnel. It was fixed perpendicularly by means of digging two holes in the soil, deep enough to take in the legs of the windbreak completely and then placing the windbreak legs in them. Afterwards the soil was refilled around the windbreak legs and the holes were closed by pressure with the feet. The height of the artificial windbreak was 70.0 cm and the width was 1.58 cm. The width of the artificial windbreak provided an ideal shelterbelt, because it got the same width as that of the wind tunnel (in theory, the ideal shelterbelt which could give the maximum protection should extend from horizon to horizon). The artificial windbreak consists of a rectangular wooden frame in

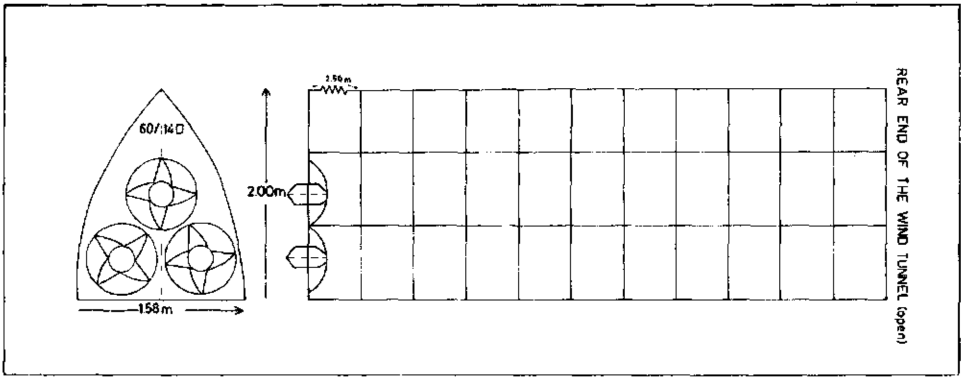


Fig. 15. Diagram showing the details of the wind tunnel at Wageningen.

which the plastic strips were running lengthwise. The air drainage through the artificial windbreak was 32%. The artificial windbreak which was used in the wind tunnel at Wageningen can be seen in fig. 16.

1.2 – Wind velocities in the wind tunnel. The wind velocities in the wind tunnel were determined by means of hand anemometers. These are simple instruments and enclosed in parts in a small metal box of measurement $11\frac{1}{2} \times 7 \times 3$ cm. The weight of the instrument is only 190 g which makes it easy to handle. A hand anemometer in the metal box can be seen in fig. 17. The hand anemometer consists of three cups which can be fixed on the counting-devise. The counting-devise can be fixed on a wooden stick by means of a screw. The hand anemometer in parts can be seen in fig. 18 and completely fixed on the stick as used in the wind tunnel experiments in fig. 19. The counting-devise has four needles, each presenting a quarter of the circle, and when the three cups start rotating due to wind, the needles in the counting-devise also start moving. By means of a stopwatch the time is recorded necessary for the needles to revolve the quarter, the half, and the complete circle. The time used for revolving a particular section of the circle indicates directly the wind velocity in m/sec from the curves on the lid of the metal box.

For determining high wind velocities, the needle in the counting-devise is allowed to

Fig. 16. The artificial windbreak used in the wind tunnel at Wageningen.

Fig. 17. The hand anemometer can be seen in the metal box. On the lid of the metal box curves can also be seen from where the direct reading for the velocity of wind can be found.

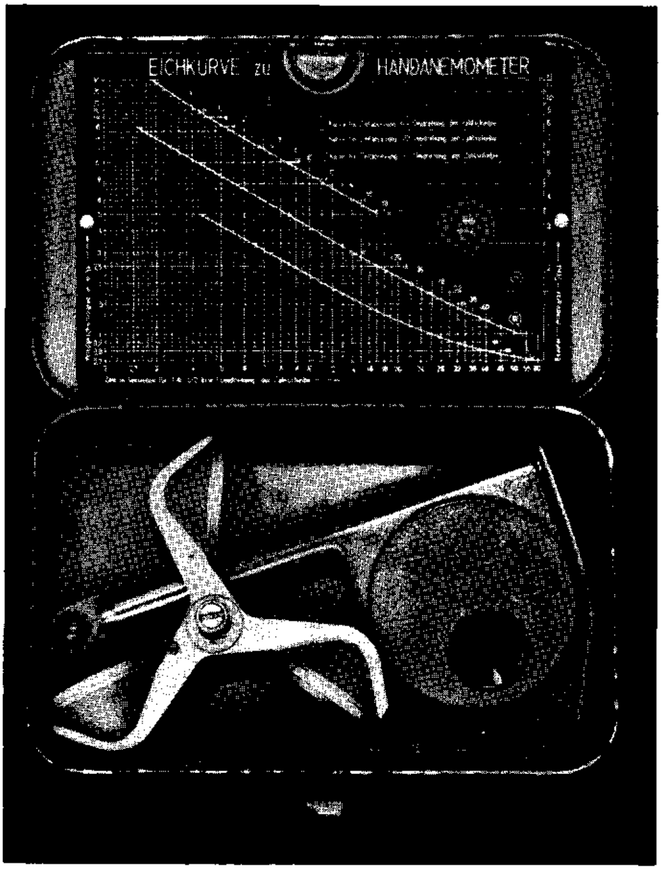


Fig. 18. Hand anemometers in parts, counting devise, three cups and screw for fastening.

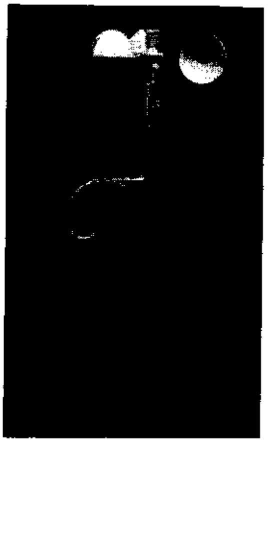


Fig. 19. Complete hand anemometer fixed on the stick as used in the wind tunnel.

revolve around the complete circle and curve I on the lid of the metal box is used for finding the wind velocity. When medium wind velocities are to be determined, the needle in the counting-devise is allowed to revolve only around half of the circle, and curve II on the lid of the metal box is used. For determining low wind velocities, the needle in the counting-devise is allowed to revolve only quarter of the circle, and curve III on the lid of the metal box is used. The maximum wind velocity which can be measured by means of the hand anemometer is 30 m/sec, and the minimum wind velocity to be recorded is 0.7 m/sec.

Intensive observations with the hand anemometers were carried out along the centre of the wind tunnel. The results indicated that the wind velocity was the same in the wind tunnel except in the region of the first 7.5 m from the fans. Therefore, the author decided not to use first 7.50 m of the wind tunnel for determining the influences of wind on the development and yield of the crops. As a consequence, the research experiments were started at 7.50 m from the fans. This 7.50 m of open area in the wind tunnel which had no vegetation, was covered with straw so that the soil was not eroded by wind.

There was also some turbulance of the wind blown in the wind tunnel. This brought the wind in the wind tunnel much closer to the natural wind where there is always some turbulance. The wind tunnel could be operated by eight different speeds. The author recorded the wind velocities in three different sections of the wind tunnel. Two hand anemometers were used at the different heights of 120 cm and 50 cm respectively. The observations were taken in three different sections, fore-end, middle and rear-end of the wind tunnel. The details of the results are given in Table 7.

Table 7 – Wind velocities in the wind tunnel with 8 different speeds of the fans

Speed number	Hand anemometers	Wind velocity at the distance from the rear end (m/sec)		
		20 m	12.5 m	3 m
1	High (120 cm)	2.0	2.5	2.4
1	Low (50 cm)	2.1	2.5	2.5
2	High (120 cm)	2.1	2.9	2.5
2	Low (50 cm)	2.4	2.9	2.9
3	High (120 cm)	2.5	3.0	2.7
3	Low (50 cm)	2.5	3.0	3.0
4	High (120 cm)	2.7	3.2	3.2
4	Low (50 cm)	2.8	3.2	3.2
5	High (120 cm)	3.0	3.5	3.4
5	Low (50 cm)	3.2	3.5	3.8
6	High (120 cm)	3.2	3.9	4.1
6	Low (50 cm)	3.5	3.9	4.4
7	High (120 cm)	3.6	4.8	4.6
7	Low (50 cm)	3.9	4.8	4.8
8	High (120 cm)	4.4	5.5	5.5
8	Low (50 cm)	5.0	5.5	6.0

The observations indicate that there was little difference between the wind velocities in the different sections, when the wind tunnel was operated with the same speed. These differences in wind velocities in the different sections of the wind tunnel were due to turbulance. The lowest wind velocity on which the wind tunnel could be operated was 2.0 m/sec, and the maximum velocity on which it could be operated was 6.0 m/sec.

The author carried out an intensive investigation to determine the influence of the windbreak on the wind velocity in the wind tunnel. Three hand anemometers of different heights i.e. of 140 cm, 60 cm and 30 cm which are expressed as A, B and C respectively were used. The wind velocity without the presence of a windbreak would have been 5.5 m/sec. Observations were taken at the distance of each 70 cm for the total distance of 17 m from the windbreak to the rear-end of the wind tunnel. Each 70 cm in the lee-section of the windbreak is expressed as 'H'. Also the observations were taken at each 70 cm distance from the windbreak towards the fans for the total distance of 4.9 m. Each 70 cm in the windward-section of the windbreak is expressed as 'W'. By marking each sampling plot of 'H' and 'W' at the distance of 70 cm, it was possible to express the experimental results in terms of the windbreak height, because this was also 70 cm. The details of the results are expressed in fig. 20.

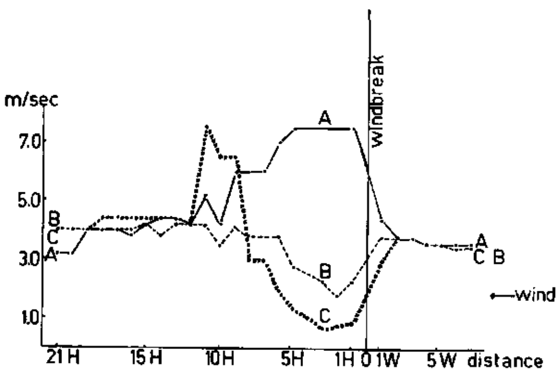


Fig. 20. The influence of the artificial windbreak on the wind velocity in the wind tunnel at Wageningen. 'H' and 'W' are the distances expressed in terms of the height of windbreak. 'A', 'B' and 'C' are the three hand anemometers fixed at the various heights.

Different circumstances in the wind tunnel resulted in lowering the protective capacity of the windbreak in terms of area as compared to the open field. It was mostly due to limited space in the wind tunnel and as a consequence there was not enough space for the windbreak to deflect the wind upward to greater distance. The force and pressure of the wind resulted in bringing down the wind currents much earlier than the anticipated greater distance of 15 to 20 times the height of the windbreak. The hand anemometer 'A' of 140 cm height showed a sudden rise of wind velocity from 4.0 m/sec at 1 W to 7.5 m/sec at 1 H which showed clearly that the wind was deflected upward by the windbreak and under force the wind gained a high velocity. In fig. 20 the hand anemometers show that the windbreak provided protection till 8 H and to some extent also up to 10 H. Also some reduction in wind velocity caused by the windbreak at 1 W can be seen in fig. 20. At the distances of 2 W, 3 W, 4 W, and 5 W, all the three hand anemometers showed the same wind velocities.

1.3 – Irrigation system in the wind tunnel. For watering the plants and also for controlling the amount of moisture given to the plants, various irrigation methods were tried out. A system of providing rain was worked out. A long pipe with nine nozzles at different distances was fixed at the roof of the wind tunnel. It can be seen in fig. 14 on p. 26. Then the rain experiments were conducted to find the distribution of the moisture in

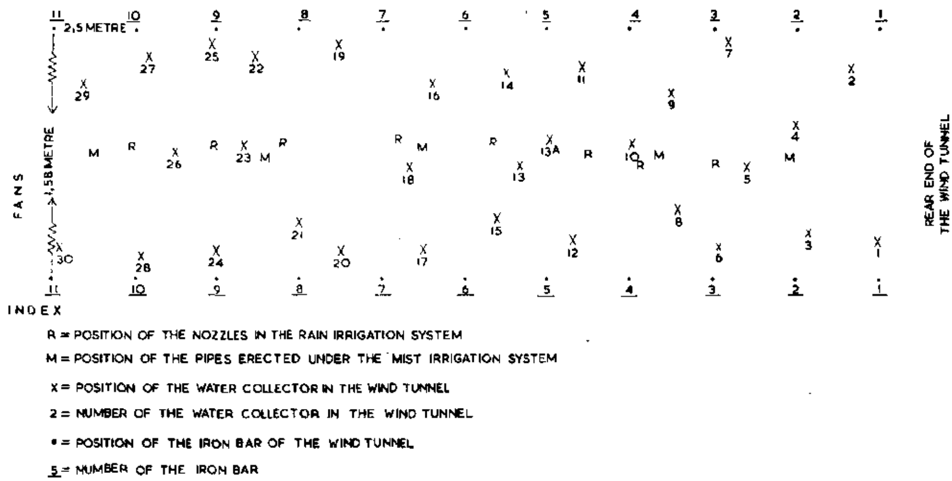


Fig. 21. Plan for the distribution of the water collectors for the rain experiments in the wind tunnel.

the wind tunnel. Thirty water collectors were distributed evenly in the wind tunnel. Fig. 21 gives the plan for the distribution of the water collectors.

The experiment was carried out under two different conditions, first with strong wind and strong water supply from the tap, and then with weak wind and weak supply from the tap. The conversion of cc water into mm of rain is given in fig. 22. The results of the experiments which are given in Table 8 indicated that the distribution of the moisture was uneven.

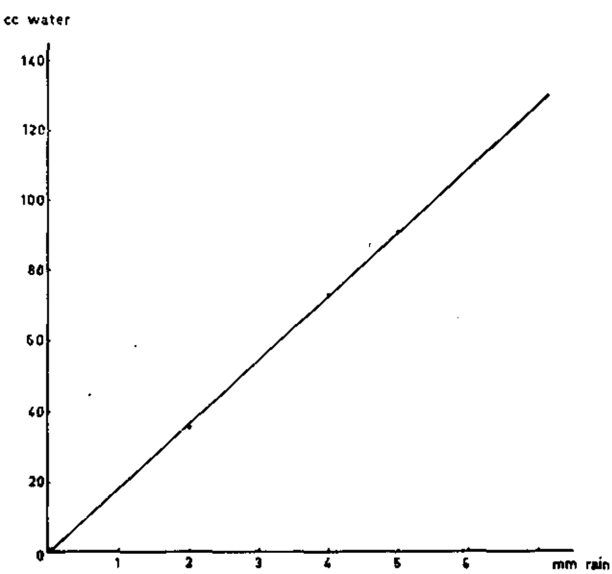


Fig. 22. Conversion of cc water into mm of rain.

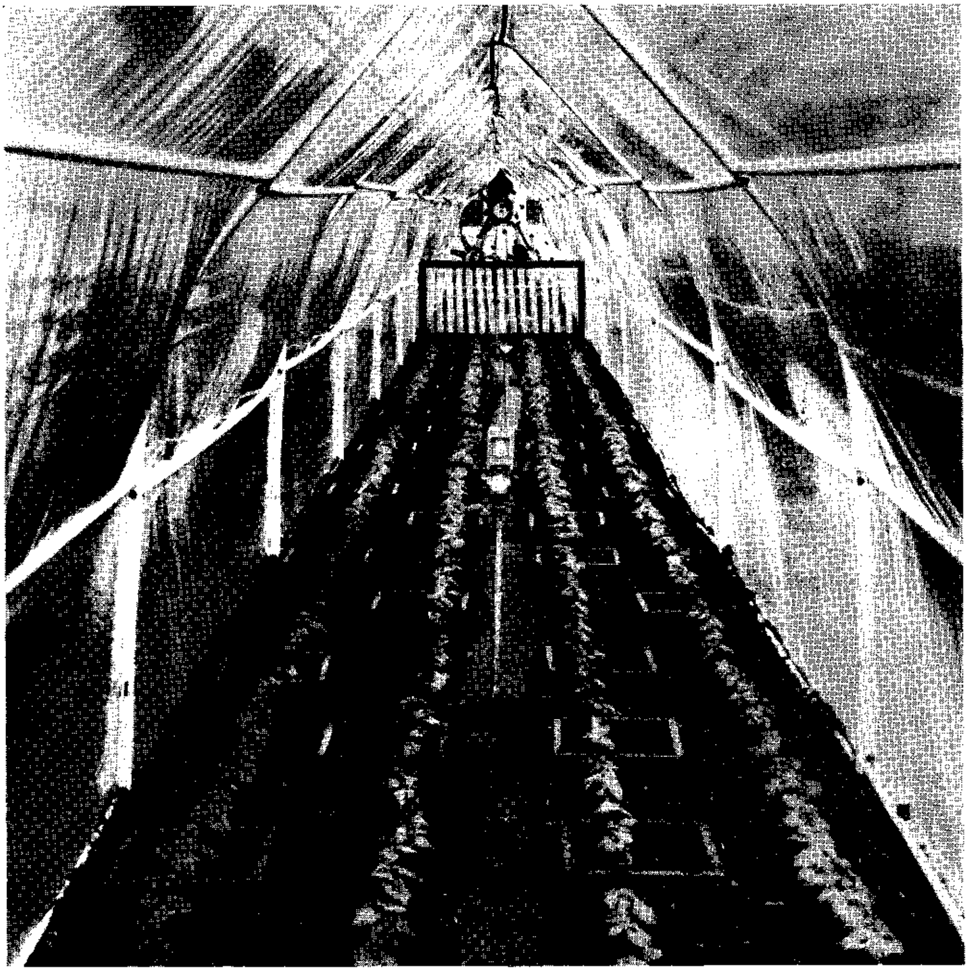


Fig. 23. Bean crop growing near to field conditions in the wind tunnel at Wageningen. The pipes with nozzles used for mist irrigation system can also be seen.

Due to the limited number of plants, only two sampling analyses were carried out, i.e. when the plants were 26 days and 46 days old respectively. The sampling was carried out both in the lee-section and the windward-section of the windbreak. Plants were collected for analyses at twenty different spots in the lee-section of the windbreak. From each spot 10 plants were taken out and then the 5 average plants were selected for the observations. The first sampling spot was located at one time the height of the windbreak i.e. at 1 H. The second and third sampling spots were located at two and three times the height of the windbreak respectively i.e. at 2 H en 3 H. Similar observations were taken from 1 H till 20 H in the lee-section of the windbreak in the wind tunnel. Similarly at seven different sampling spots towards the windward side of the windbreak observations were recorded. The first sampling spot in the windward side was located at one time the height of the windbreak i.e. at 1 W, and so on.

When the plants were 104 days old and the crop was harvested, the yield determination was carried out. The wind tunnel was divided into two equal halves for the purpose of taking observations. The samplings were carried from 1 H till 20 H, also from 1 W till 7 W, both in the eastern and the western side of the wind tunnel. In each sampling 10 plants were taken out and 5 were selected for observations.

2.2 – Discussion of results. When the plants were 26 days old, the influence of the windbreak could be seen very sharply. Fig. 24 shows the development of leaves when the plants were 26 and 46 days old. When the plants were 26 days old, the number of leaves in the windbreak protected area up to 8 H was 20% higher as compared with the unprotected area in the wind tunnel. The influence of the windbreak looked to be negative when the plants were 46 days old, but actually the leaves started falling earlier in the protected area than in the unprotected area. The fall of leaves started because the plants were almost completely mature whereas in the non-protected zone the plants were still in the earlier developmental phases.

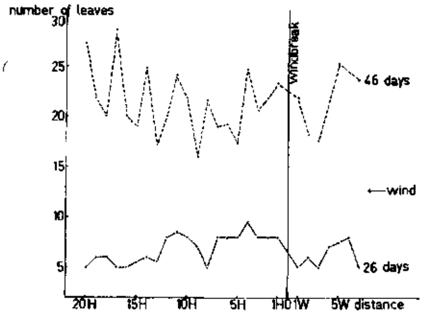


Fig. 24. The development of number of leaves of bean crop under the influence of the windbreak in the wind tunnel at Wageningen when the crop was 26 or 46 days old.

[1]

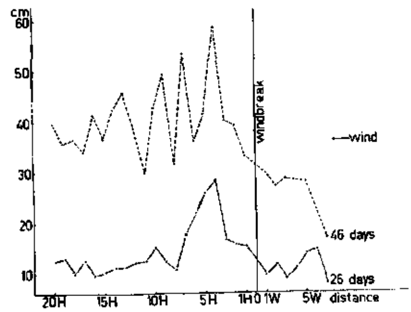


Fig. 25. The development of the height to the last node of bean crop under the influence of the windbreak in the wind tunnel at Wageningen when the crop was 26 or 46 days old.

The plants in the protected zone were more than 31% higher as compared to the plants growing in the unprotected zone of the wind tunnel. Fig. 25 shows the development of the height to the last node when the plants were 26 and 46 days old respectively. The plants in the protected zone maintained their lead of more than 52% in height over the plants of the unprotected zone when 46 days old.

The numbers of nodes were 54% higher in the protected zone as compared with the unprotected zone plants. Fig. 26 illustrates this fact very clearly, when the plants were 26 days old. The lead in nodes was lost when the plants were 46 days old.

The wet weight, dry weight and percentage dry weight of the bean crop were also recorded when the sampling analysis of the plants of 46 days old was carried out. Figures 27, 28 and 29 give the results of wet weight, dry weight and percentage dry weight of plants respectively, when they were 46 and 104 days old. The plants maintained their lead in 20% higher wet weight from the age of 46 days old till the 104 days age of har-

[1] Due to misprinting the graphline has been broken.

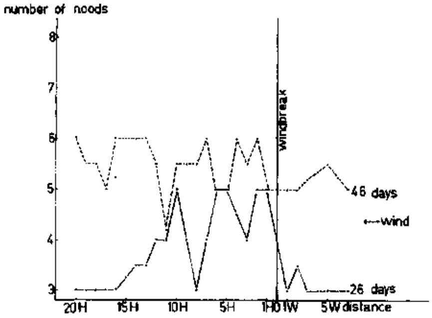


Fig. 26. The development of the number of nodes of bean crop under the influence of the windbreak in the wind tunnel at Wageningen when the crops were 26 or 46 days old.

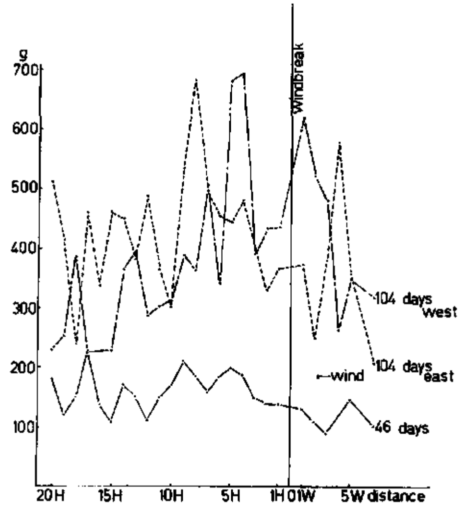


Fig. 27. The development of the wet weight in bean crop under the influence of the windbreak in the wind tunnel at Wageningen when the crop was 46 or 104 days old. East and West are east and west sides of wind tunnel.

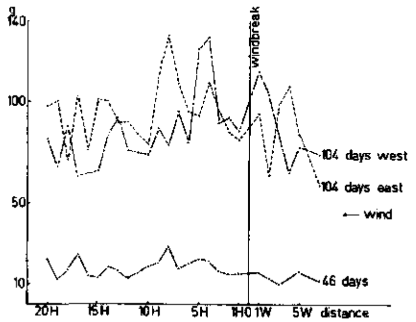


Fig. 28. The development of the dry weight in bean crop under the influence of the windbreak in the wind tunnel at Wageningen when the crop was 46 or 104 days old. East and West are east and west sides of wind tunnel.

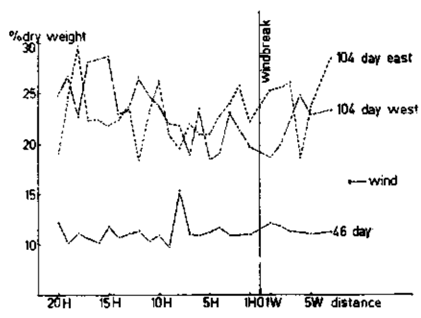
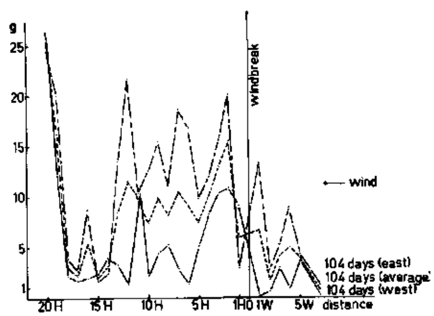


Fig. 29. The development of the percentage dry weight in bean crop under the influence of the windbreak in the wind tunnel at Wageningen when the crop was 46 or 104 days old. East and West are east and west sides of wind tunnel.

Fig. 30. The yield of bean seeds (dry weight) under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and West sides of wind tunnel.



vesting. The dry weight was about 54% higher when the plants were 46 days old, but the lead was reduced to 17% when the plants were 104 days old. The percentage dry weight goes down because the water-content is higher in the plants of the protected zone. Fig. 29 indicates this fact clearly.

Fig. 30 shows the final yield. There was 67% higher yield in the protected zone as compared with the unprotected plants in the wind tunnel. In fig. 30 the yield is also seen very high at 20 H, which is contributed to its location little out of the wind tunnel where the wind velocity was also very low.

2.3 – Conclusions. The development of the plants under the protection of the windbreak was better as compared to the plants in the unprotected zone of the wind tunnel. The greater number of leaves and bigger size of the plants in height and weight contributed to its increased photosynthetic area which further helped the plants to produce more carbohydrates for their better growth and development. The yield of seeds was 67% higher as compared with the yield of the unprotected zone.

3 – Development and yield of bean crop in pots in the wind tunnel

3.1 – Methods, observations, presentation of material. The irrigation system in the experiment on development and yield of bean crop under field condition in the wind tunnel was not perfect. Therefore the author decided to repeat the experiment by growing the bean crop in clay pots. Each pot was manually irrigated and a fixed amount of water was added to each pot. The amount of watering to the pots was recorded. All the pots in the east side were watered with the same amount of water. Similarly all the pots in the west side were watered with the same amount of water. But the pots located in the west side were irrigated with less water as compared with the pots of the east side.

Fifty clay pots were made ready for the experiment. Each pot was filled with the same type of soil. Each pot was also treated with the same amount of fertilizer. Twenty-five pots were placed in the east side of the wind tunnel, 20 in the lee-section of the windbreak i.e. 1 H till 20 H, 5 in the windward-section of the windbreak i.e. 1 W till 5 W. Similarly, the other 25 pots were placed in the west side of the wind tunnel. Each pot in the wind tunnel was sunken into soil by means of digging a hole in the ground. In fig. 31

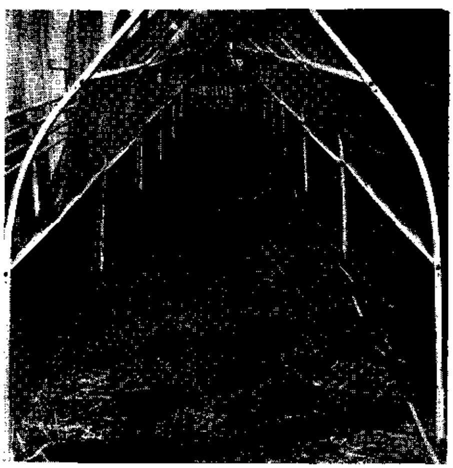


Fig. 31. The clay-pots sunk into the soil of the wind tunnel at Wageningen.

pots sunk in the soil can be seen. The space between the pots was covered with straw so that no soil erosion could take place. The straw was fixed on the ground by means of a net. But the net kept the pot surface free for the plant growth.

On August 16, 1960, fifteen seeds were sown in each pot. The seeds were allowed to germinate without wind treatment. When the seeds had germinated, the wind tunnel was operated on the same schedule as was used for the experiment on development and yield of bean crop in field conditions. Two weeks later, the thinning operation was carried out: the best 5 plants were kept in each pot and the remaining were taken out. The plants growing in the pots in the wind tunnel can be seen in fig. 32.

No sampling analysis was carried out during the developmental period of the bean crop

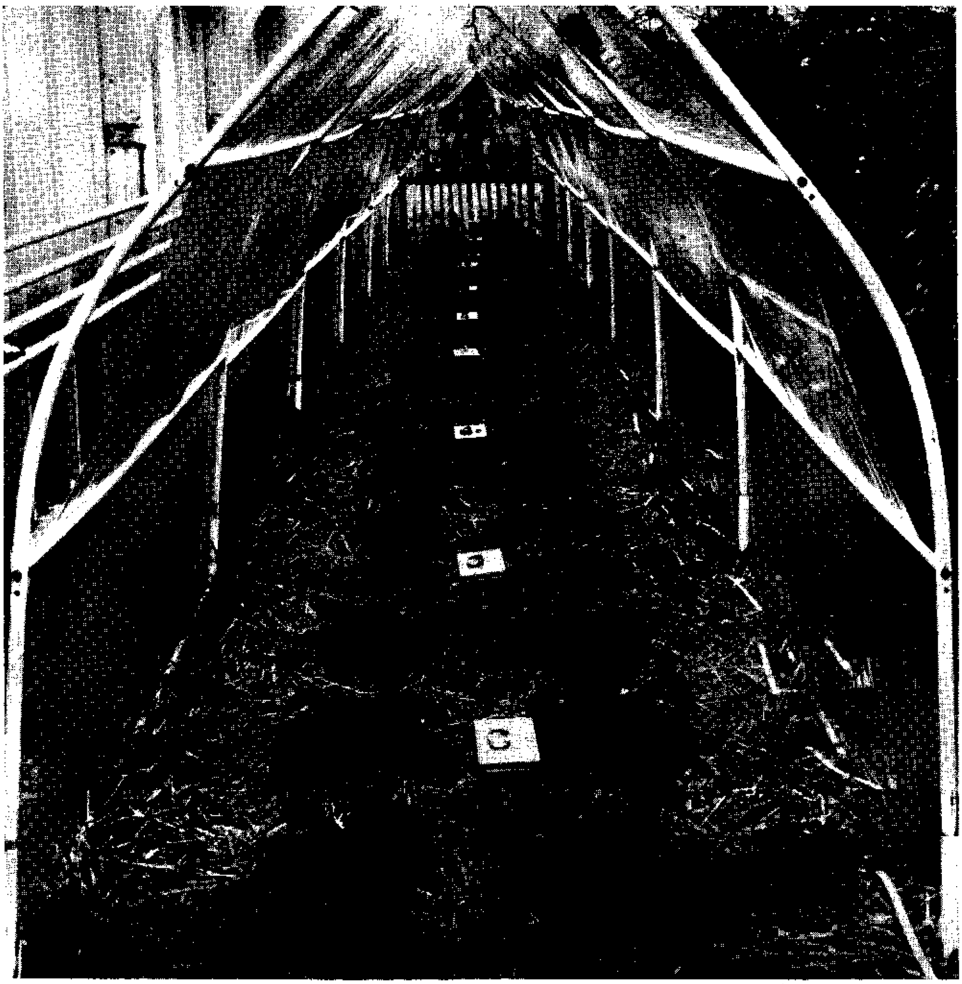


Fig. 32. The bean plants growing in the pots in the wind tunnel at Wageningen. The influence of the windbreak is visible.

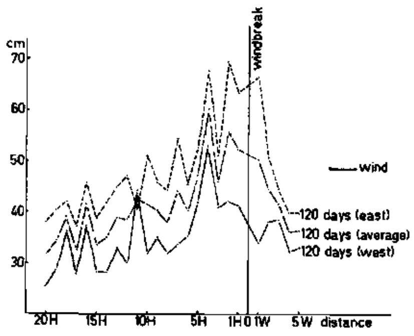


Fig. 33. The height of bean crop 120 days old in pots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

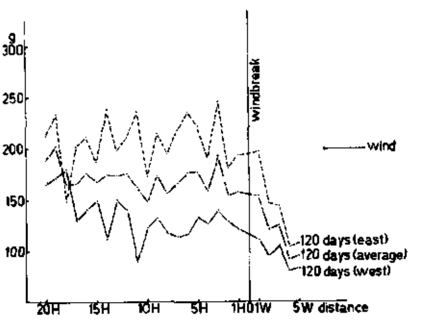


Fig. 34. The wet weight of bean crop 120 days old in pots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

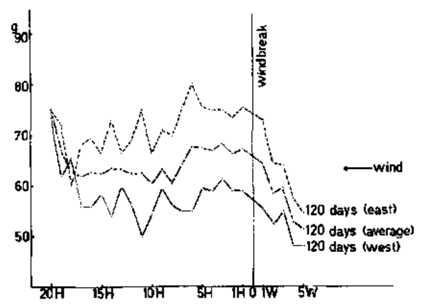


Fig. 35. The dry weight of bean crop 120 days old in pots under the influence of the wind break in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

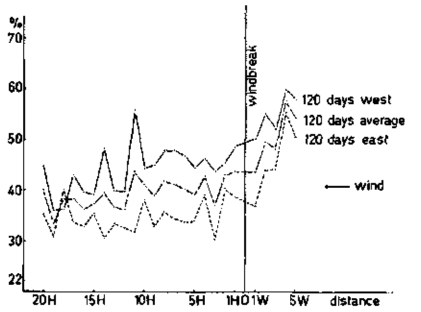


Fig. 36. The percentage dry weight of bean crop 120 days old in pots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

in pots. But close observations were kept by the author. The growth of the plants was much better in the protected zone of the windbreak as compared to the non-protected zone in the wind tunnel. When the crop was 120 days old, the detailed growth and yield analysis was carried out.

3.2 – Discussion of results. Bean plants were 16% higher in the wind protected zone, i.e. up to the distance of 10 H, as compared with the bean plants in the unprotected zone in the wind tunnel. The pots in the east side of the tunnel showed more superior growth in height which can be very clearly seen in fig. 33.

But the trend of the protection provided by the windbreak in the wind tunnel is similar in both cases. The wet weights of the plants were 34% higher in the protected zone than in the unprotected zone, but the lead in dry weight was only 14%.

The major reason for such a low influence of the windbreak on the dry and wet weight of plants was that the leaves started falling earlier in the protected zone as compared with the unprotected zone. The number of pods was 19% higher in the protected zone of the wind tunnel than in the unprotected zone.

The wet weight of bean pods was 20% higher and the dry weight of the pods was 34% higher in the protected zone of the windbreak as compared with the pods of the unprotected zone of the wind tunnel.

The number of seeds up to 5 H was 28% higher as compared with the unprotected zone of the wind tunnel. But from 5 H till 9 H, they were only 16% higher. The yield of bean seeds in dry weight was 28% higher in the protected zone, i.e. up to 8 H, as compared with the unprotected zone of the wind tunnel.

The yield of bean seeds was 32% and 25% higher in the east and west protected sections of the tunnel respectively. The greater amount of the high quality bean seeds, determined by sieving, was in the protected zone of the windbreak and the greatest amount of low quality seeds in the unprotected zone of the wind tunnel.

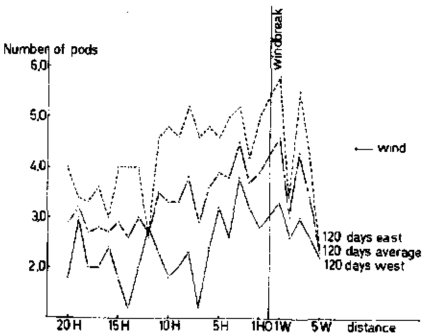


Fig. 37. The number of bean pods 120 days old in pots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

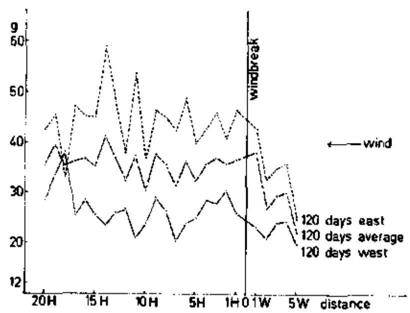


Fig. 38. The wet weight of bean pods 120 days old in pots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

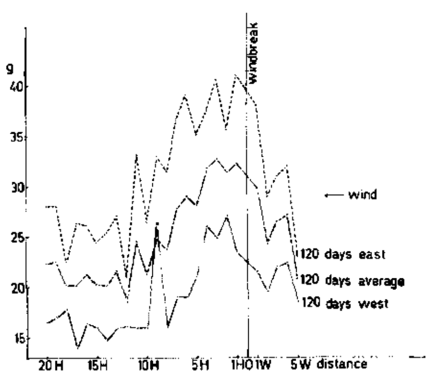


Fig. 39. The dry weight of bean pods 120 days old in pots under the influence of windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

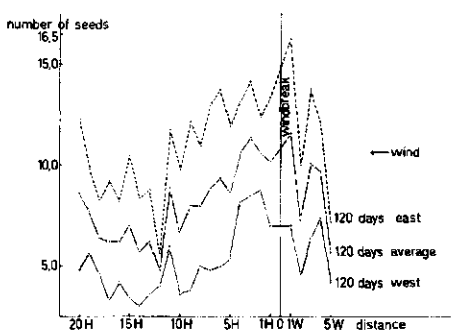


Fig. 40. The yield as number of bean seeds in pots under the influence of windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

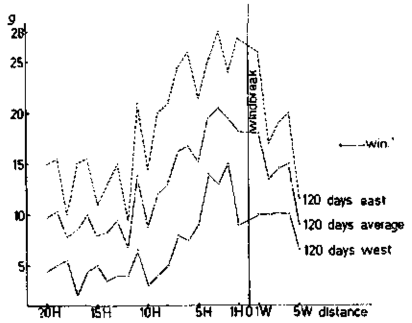


Fig. 41. The yield of bean seeds (dry weight) in pots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

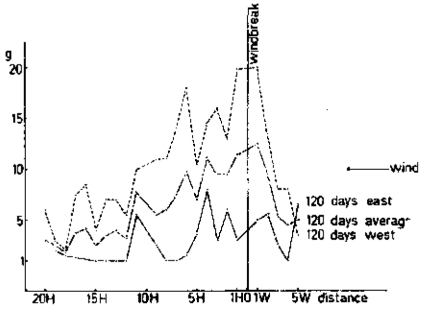


Fig. 42. The yield of high quality bean seeds in pots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

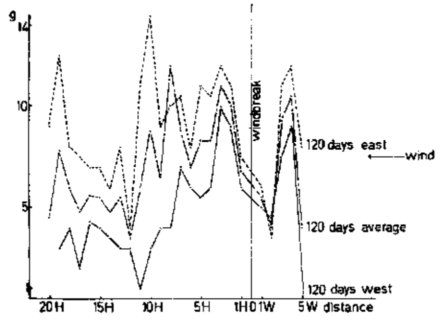


Fig. 43. The yield of low quality bean seeds in pots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

3.3 – Conclusions. The growth and development of the bean plants were better in the protected zone of the windbreak as compared to the non-protected zone in the wind tunnel. The yield of bean seeds was 28% higher. Also most of the high quality bean seeds were found in the protected zone of the windbreak as compared to the non-protected zone in the wind tunnel.

4 – Development of the maize crop in pots in the wind tunnel

4.1 – Methods. The variety of maize seeds selected for the research in the wind tunnel and later for field experiments was Pioneer X 6132. This variety was selected because it gives an almost homogeneous crop which makes it easier for determining the influence of the windbreak on its development. Moreover this variety also suits the Netherlands climate well.

Fifty pots in the wind tunnel were filled with the same type of soil. Later all the pots were treated with the same amount of fertilizer. Ten seeds were sown in each pot. Seeds were allowed to germinate without wind treatment. When the seeds had germinated, the wind tunnel was operated on the same schedule as was used for the experiments with beans. When the plants were two weeks old, the thinning operation was carried out. The best five plants were kept in each pot and the rest was thrown out.

The pots situated on the east side of the wind tunnel were irrigated with 200 cc of water per pot, and the pots which were situated on the west side of the wind tunnel were irrigated with 100 cc per pot per day.

No sampling analysis was carried out in the earlier developmental period of the maize crop. But the author kept very close observations on the development of maize under the influence of the windbreak. The author was able to notice that the maize plants under the protection of the windbreak in the wind tunnel were leading in growth over the unprotected plants. As the artificial windbreak was only 70 cm in height, the author decided to make the final development analysis as soon as some plants would reach close to the height of the windbreak in the wind tunnel. It was unfortunate that the dimensions of the wind tunnel made it impossible to study the yield analysis of maize crop. But still the results from the development analysis indicate very clearly how the maize plants reacted to the protection provided by the windbreak.

4.2 – Discussion of results. The number of leaves was 10% higher in the protected zone, i.e. up to 9 H, of the wind tunnel as compared with the non-protected zone of the east side of the wind tunnel.

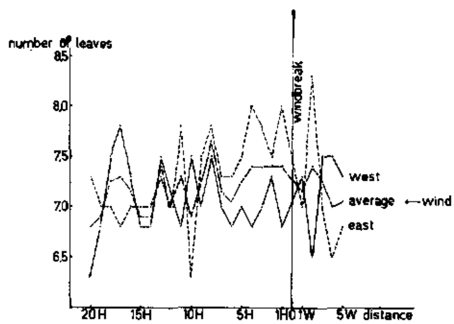


Fig. 44. The numbers of leaves of maize crop under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

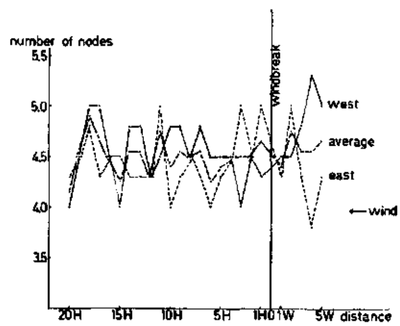


Fig. 45. The numbers of nodes of maize crop under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

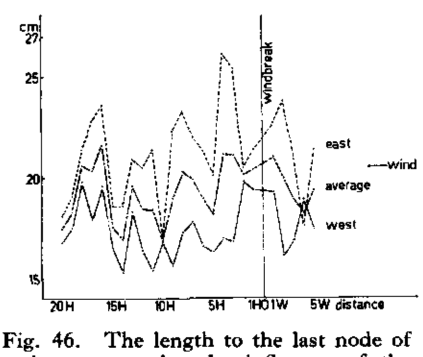


Fig. 46. The length to the last node of maize crop under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

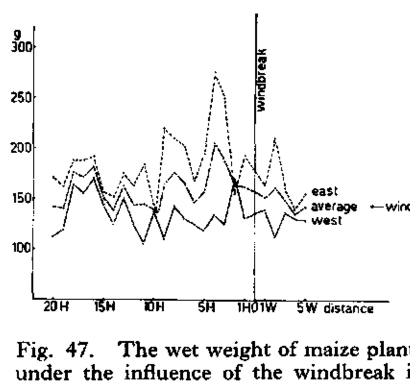


Fig. 47. The wet weight of maize plants under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

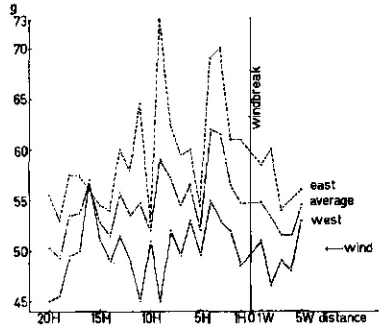


Fig. 48. The dry weight of maize plants under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

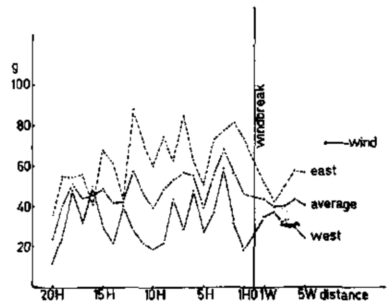


Fig. 49. The wet weight of maize roots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

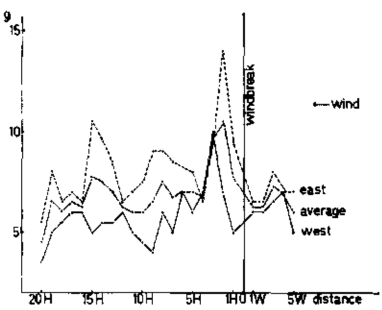


Fig. 50. The dry weight of maize roots under the influence of the windbreak in the wind tunnel at Wageningen. East and West are east and west sides of wind tunnel.

But the lead in number of leaves was only 8% in the protected zone of the windbreak as compared with the unprotected zone in the west side of the wind tunnel. There was no significant increase in the number of the nodes in the protected zone of the wind tunnel.

But in height the maize plants of the protected zone of the windbreak were on lead by 15% over the maize plants in the unprotected zone in the east side of the wind tunnel, whereas the lead of the protected plants in the west side of the tunnel was only 5%.

The total wet weight of maize crop showed 18% increase in the wet weight of plants which were under the protection of the windbreak as compared to the maize plants which were non-protected in the eastern side of the wind tunnel. Whereas the increase in the wet weight of maize plants in the western side of the wind tunnel was 8% under the influence of the windbreak. The dry weight of the maize plants under the protection of the windbreak was 11% higher as compared to the unprotected maize plants in the eastern side of the wind tunnel.

The dry weight of the maize plants in the protected zone of the windbreak was only 5% higher as compared among the maize plants in the western side of the wind tunnel. The development of roots was also better in the windbreak protected area of the wind tunnel.

Fig. 51. The influence of the windbreak on the growth of maize in the wind tunnel. The left pot was under the protection of windbreak and the right pot was under the unprotected zone of the wind tunnel. Both pots were irrigated with 200 cc of water per day.

Fig. 52. The influence of the windbreak on the growth of maize in the wind tunnel under low moisture conditions. The left pot was under the protection of the windbreak and the right was under the unprotected zone in the wind tunnel. Both pots were irrigated with 100 cc of water per day.

In fig. 51 the photograph of two pots from the eastern side of the wind tunnel where the pots were irrigated with 200 cc of water can be seen. The left pot was under the protection of the windbreak and the right pot was in the unprotected zone of the wind tunnel. The maize plants under the windbreak protection can be seen growing luxuriously and the plants growing in the unprotected zone look comparatively poor.

In fig. 52 the photograph of two pots from the western side of the wind tunnel where the pots were irrigated with 100 cc of water can be seen. The left pot was under the protection of the windbreak and the right pot was in the non-protected zone of the wind tunnel. In the western side of the wind tunnel, the difference between the growth of plants in the protected and non-protected zones of the wind tunnel is less sharp. This difference is due to the irrigation with a lower amount of water. The other factor which combined with it was that the wind velocity was also a little higher on the western side of the wind tunnel as compared with the eastern side.

4.3 – Conclusions. The development of the maize crop was much better and luxurious under the protection of the windbreak as compared with the maize crop growing in the unprotected zone of the wind tunnel. Leaves were 9%, height 15% in the eastern side and only 5% in the western side more in the protected area of the wind tunnel as compared with the non-protected zone. The yield of dry weight of maize plants was 11% in the eastern part with sufficient water, and 5% in the western part with insufficient water, higher in the protected zone of the wind tunnel as compared with the non-protected zone.

5 – Summarizing conclusions

The windbreak in the wind tunnel reduced wind velocities up to the distance of 10 H in the wind tunnel at Wageningen. Although a mist irrigation system was better than a rain system, still it was not perfect. Manual irrigation in the wind tunnel proved to be the best compared with any automatic system of irrigation.

The growth of the bean crop in field conditions under the protection of the windbreak was better as compared with the bean crop in the non-protected zone of the wind tunnel. The yield of bean seeds was 67% higher in the protected zone as compared to the yield from the non-protected zone in the wind tunnel.

The growth of bean crop in pots was also better in the windbreak protected zone as compared with the non-protected zone of the wind tunnel. In this case the yield of bean seeds was 28% higher in the protected zone of the windbreak as compared with the non-protected zone of the wind tunnel. The reason for the lower yields in pot experiments as compared to the yield of bean crop in field conditions was due to a late start in growing season of pot experiment. Consequently the bean plants in pot experiments faced the setback of smaller day length, lower light intensity and temperature, which resulted in lower yields.

The growth of maize crop was also much better under the protection of the windbreak in the wind tunnel as compared to the maize plants growing in the non-protected zone. The yield of dry weight of maize plants was 11% higher in the eastern part, and 5% higher in the western part of the protected zone of the wind tunnel as compared with the non-protected zone of the wind tunnel.

There is no doubt from the above results of the experiments that when the windbreak protects the crop, the growth and yield of the crop go up very high. Now the question arises, what factors are influenced by the windbreak which cause the increase of the yield of crops. The author will bring forward and discuss in the next chapter some factors which are influenced by the windbreak and will also explain how they react to bring better yields in the crops.

Chapter V

THE MAJOR FACTORS INFLUENCED BY THE SHELTERBELT WHICH ARE RESPONSIBLE FOR THE BETTER DEVELOPMENT AND THE INCREASE OF THE YIELD OF CROPS

1 – Temperature

Methods. For determining the influence of the windbreak on the temperature, ten thermographs were placed at different places in the wind tunnel at Wageningen, some in the windbreak protected zone and others in the non-protected zone. The photograph of one of the thermographs can be seen in fig. 53.

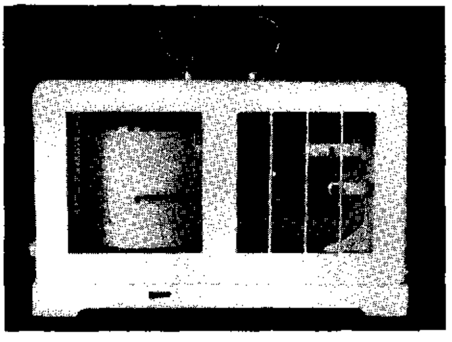


Fig. 53. One of the ten thermographs (the self registering thermometers) used in the wind tunnel at Wageningen.

The temperatures were recorded for a week. The average results from the one week observations are given in Table 9 which clearly shows that the temperature in the windbreak protected zone was 3–5° C higher as compared with the non-protected zone. Van der Linde and Woudenberg (138) also found higher temperatures under the protection of the windbreak in field conditions.

Table 9 – The influence of the windbreak on the temperature in the wind tunnel at Wageningen

Distance from the windbreak	Temperature in °C
2 W	30
6 W	30
1 H	35
3 H	33
5 H	34
7 H	34
9 H	32
11 H	32
14 H	32
17 H	30

VAN DER LINDE (139) also pointed out that the shelterbelts not only reduce the horizontal component of the air movement, but also the turbulance in the lowermost air layer, and thus reduce vertical heat transport.

For determining the influence of the temperature on the growth of his experimental plants, the author conducted a series of experiments under the temperatures of 10° C, 15° C, 16° C, 20° C, and 25° C to study the growth and development of bean and maize crops. The temperature experiments were conducted in the climatic rooms and the glasshouses of the Institute for Biological Research of Field Crops (I.B.S.) at Wageningen.

Thirty-two soil pots were prepared for conducting experiments with bean and maize crops in two climatic rooms with temperatures of 15° C and 20° C respectively. Sixteen pots were used for the bean crop and the remaining sixteen for the maize crop. The particulars of pot filling are as follows:

Pot + Gravel	= 2.5 kg
Soil	= 6.0 kg
Total weight	= 8.5 kg

The above soil was then mixed with 8.5 g of superphosphate (1.5 g of P_2O_5) and with 5.0 g potash (1.3 g of K_2O). Later each pot was treated with 350 mg of potassium nitrate per pot. The light in the climatic rooms was given from tube lights for 17 hours per day. The intensity was 15000/ergs/sq cm/sec. Eight sampling analyses of bean and maize crops were carried out.

Forty soil pots were made ready for conducting experiments in three glasshouses with temperatures of 10° C, 16° C and 25° C respectively. The pot filling and the nitrate treatment to the soil pots were the same as for the climatic room experiments. The plants used the normal daylight and at night the light was provided from tubes. Thus the plants were given light for 24 hours. The intensity of tube light was 1000 ergs/sq cm/sec. The soil pots were divided into two equal halves for the use of bean and maize crops.

Eight pots of each crop were put into the glasshouse, where the temperature was 25° C. Ten pots of each crop were put into the glasshouse with 16° C. The remaining two pots of each crop were put into the glasshouse where the temperature was 10° C. Ten sampling analyses of each crop were carried out.

Discussion of results. The details of the results are pointed out in the Tables 10, 11, 12, and 13.

The plants with the different temperatures showed sharp differences in their growth rates. The plants of bean and maize crops at higher temperature took the lead over the plants at lower temperature. The flowering of bean and maize plants was earlier under high temperatures. The growth cycle was also shortened under higher temperatures. Dry weight of plants and the yield of bean crop was higher under high temperature as compared with low temperature. Higher temperatures also resulted in most vigorous growth and a rapid increase in heights of the plants. With the descent of temperature, the growth became slower and the increase in height was also reduced.

The optimum temperature influences the set of pods more than relative humidity, soil moisture, fertilizer, while the percent set of pods can be predicted from the optimum temperature with a fair degree of accuracy (65). The apparent photosynthesis increases to a maximum as the temperature increases and then declines rapidly as the temperature continues to increase (152). The maximum rate of apparent photosynthesis may vary from below 10° C for cold-adapted (cryophilic) plants through approximately

Table 10 – THE INFLUENCE OF 15° AND 20° ON THE DEVELOPMENT OF BEAN CROP (AVERAGE PLANT) AT DIFFERENT AGES

Age (in days)	9		17		22		28		37		46		53		62	
Temperature	15°	20°	15°	20°	15°	20°	15°	20°	15°	20°	15°	20°	15°	20°	15°	20°
Number of leaves	2.0	2.3	3.0	4.0	5.0	11.0	8.0	15.0	11.0	17.0	12.5	19.0	12.5	20.0	17.0	20.0
Number of nodes	2.0	3.0	3.0	5.0	4.0	5.5	5.0	6.5	5.5	6.5	5.5	6.5	5.5	6.5	7.0	6.5
Height to the last node (cm)	6	11.5	10	33	15	50	22	62	30	68	30	68	35	62	56	62
Wet weight (g) *	7.8	16.9	12.8	21.6	17.3	31.7	24.9	51.8	37.1	51.7	69.0	130.9	61.4	141.2	—	—
Dry weight (g) *	1.0	1.4	1.5	1.8	2.0	3.1	2.9	5.4	3.7	5.8	7.7	14.6	6.8	17.4	—	—
Number of inflorescences	—	—	—	—	—	—	—	2.0	—	3.5	3.0	5.0	3.0	5.0	4.0	3.0
Number of flower buds	—	—	—	—	—	—	—	7.0	—	2.5	—	—	—	4.0	—	—
Number of flowers	—	—	—	—	—	—	—	1.0	—	3.0	—	—	—	4.0	—	—
Number of pods	—	—	—	—	—	—	—	—	—	3.0	—	7	—	5	4	4
Number of seeds	—	—	—	—	—	—	—	—	—	—	—	—	—	15	12	12

* Wet and dry weights are given of five plants

Table 11 – The influence of 15° and 20° on the development of maize crop (average plant) at different ages

Age (in days)	13		22		28		36		44		49		72		84	
Temperature	15°	20°	15°	20°	15°	20°	15°	20°	15°	20°	15°	20°	15°	20°	15°	20°
Number of leaves	3.0	4.0	4.0	7.0	5.0	7.0	6.0	9.0	7.0	10.0	8.0	11.0	8.0	11.0	8.5	12.5
Number of nodes	2.0	2.0	2.0	3.5	3.0	4.0	3.5	5.0	4.0	6.0	4.5	10.5	4.5	10.5	4.5	12.5
Height to the last node (cm)	5.5	11.5	9.5	19.0	12.5	22.0	14.5	30.5	19.5	36.5	21.5	40.0	21.5	81.5	—	—
Wet weight (g) *	0.6	2.9	2.3	13.2	4.3	16.5	3.1	32.3	10.5	38.9	—	—	15.0	65.4	15.6	—
Dry weight (g) *	0.1	0.2	0.3	0.9	0.4	1.3	0.7	3.1	1.0	3.4	—	—	1.6	12.4	—	—

* Wet and dry weights are given of five plants

Table 12 – THE INFLUENCE OF 16° AND 25° ON THE DEVELOPMENT OF BEAN CROP (AVERAGE PLANT) AT DIFFERENT AGES

Age (in days)	26		32		39		46		53		60	
Temperature	16°	25°	16°	25°	16°	25°	16°	15°	16°	25°	16°	25°
Number of leaves	8.0	26.0	10.4	31.6	22.0	33.6	23.6	23.0	28.0	14.0	22.6	9.8
Number of nodes	4.5	6.4	5.4	6.2	5.0	6.0	5.0	5.5	5.0	6.0	6.0	6.0
Height to the last node (cm)	26.5	67.0	45.6	68.2	48.5	68.6	49.0	65.4	53.0	57.8	66.4	65.4
Wet weight (g) *	45.6	140.4	97.6	173.6	118.6	231.5	157.2	193.4	161.8	179.5	204.1	195.3
Dry weight (g) *	6.3	20.0	14.9	28.6	23.9	35.8	30.2	34.9	35.2	38.7	34.6	36.9
Number of inflorescences	3.5	9.8	4.8	11.8	8.2	—	8.2	8.0	7.5	8.0	7.4	6.4
Number of buds	—	13.6	—	3.2	7.7	—	3.8	—	1.7	—	—	—
Number of flowers	—	2.4	—	5.2	—	—	8.0	—	1.0	—	1.6	—
Number of pods	—	—	—	16 0	—	—	5.0	7.0	13.0	7.5	12.6	5.6
Number of seeds	—	—	—	—	—	—	—	22.0	—	22.0	17.4	16.8

* Wet and dry weights are given of five plants

Table 13 – The influence of 16° and 25° on the development of maize crop (average plant) at different ages

Age (in days)	10		20		27		34		41		48		62		90		111	
Temperature	16°	25°	16°	25°	16°	25°	16°	25°	16°	25°	16°	25°	16°	25°	16°	25°	16°	25°
Number of leaves	1.5	2.5	3.5	5.4	6.5	9.0	8.5	12.5	9.5	13.0	10.6	15.0	12.8	13.8	13.4	14.0	11.8	13.0
Number of nodes	1.0	1.0	2.0	3.5	4.0	5.0	5.0	6.5	3.8	9.0	4.5	12.8	9.0	11.4	10.0	11.8	9.8	10.4
Height to the last node (cm)	3.0	6.0	5.0	19.1	11.2	32.4	26.5	67.6	33.7	75.7	38.6	128.5	63.5	152.9	114.2	148.6	90.2	132.6
Wet weight (g) *	0.3	0.8	7.9	61.3	41.1	278.7	570.0	224.2	558.1	538.0	450.0	550.0	520.0	503.0	450.0	373.0	377.0	250.0
Dry weight (g) *	0.1	0.1	0.8	5.4	4.0	30.7	158.1	48.0	143.7	97.4	123.9	145.6	142.5	142.4	121.6	165.7	121.0	132.0

* Wet and dry weights are given of five plants

20° C to 40° C for moderate climate plants and from 40° C to 50° C for some desert plants (152). Investigations have shown that within the optimum range for growth the rate of cell division is directly proportional to the temperature (76).

OVERBEEK (168) pointed out that in recent years evidence has accumulated that uptake of auxins is a two-step process. The first step is adsorption which is rapid and of physical nature. The second step is metabolic which is complicated, slow and steady. Uptake of growth regulators is temperature dependent. In the first step, the temperature has very little effect, but it plays a highly important part during the second step, because the permeation of the growth regulators through the layers of fatty molecules is highly temperature dependent. The experiments showed that absence of light and decrease in temperature reduced absorption of 2.4-dichlorophenoxyacetic acid (2.4-D) took place in bean plants (156).

Conclusions. The temperature in the wind tunnel increased 3° C to 5° C in the protected zone of the windbreak. From the experiments with bean and maize crop under various temperatures, the author concluded that the higher temperature gives rise to more luxurious growth of plants. Hence the rise of temperature in the protected zone of the shelterbelt is one of the major factors which contributes for the better development and high yield of the crops in the protected zone of the shelterbelt.

The importance of the influence of the shelterbelt on temperature should not be underestimated. Temperature is the 'Master Factor' in the distribution of vegetation over the earth, although its action is always interwoven with those of light and water.

2 – TRANSPIRATION

Methods. For investigating the influence of the windbreak on transpiration, an experiment was conducted in the wind tunnel. The rate of transpiration was determined at 25 different points, 20 on the leeward side of the windbreak, i.e. from 1 H till 20 H and 5 on the windward side i.e. from 1 W till 5 W. Ten seeds of bean crop were sown in each of 50 pots and grown in a controlled environment. Two weeks after the germination of seeds, only the best 5 plants were kept in each pot and the others were thinned out. After 5 weeks, when the plants were grown to a reasonable size, 25 pots containing 5 plants each were selected for conducting a rate-of-transpiration experiment in the wind tunnel. The size of each leaf on every plant was recorded in all the pots by drawing their sizes on paper. These measurements were kept for making the final adjustments in the rate of transpiration if some plants had an abnormal amount of leaf surface. Each of the 25 pots was covered with colourless plastic material except for two small orfices which were kept for adding water. These two openings were closed with two corks. The colourless plastic material passed around the stems of the plants near the surface of the pot and hence left free all plant parts above the pot. All the 25 pots with plants were weighed and then 200 cc of water was added to each. All the pots were weighed again. Then these pots were placed in the wind tunnel at the 25 different experimental points. The pots with the plants in the wind tunnel were treated for 9 hours during the daylight with a wind velocity of 5 metres per second and the remaining 15 hours without wind. After 24 hours, the pots were removed from the wind tunnel and weighed again. The amount of water transpired was calculated from the difference between the first weighing of the pot with 200 cc of water before placing in the wind tunnel and the final weighing of the pots after the 24 hours treatment in the wind tunnel. The above experiment for determining the rate of transpiration was repeated for 12 times. The average results are expressed in fig. 54.

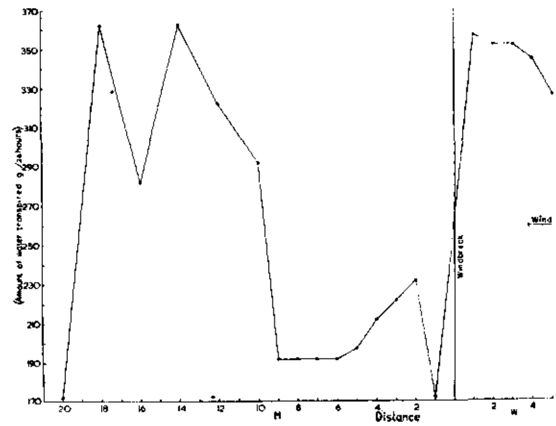


Fig. 54. The influence of the windbreak on the rate of transpiration in the wind tunnel at Wageningen.

Results of discussion. Fig. 54 clearly indicates that the rate of transpiration is about 50% higher in the unprotected zone as compared to the protected zone in the wind tunnel. When air movement is rapid, the molecules of water vapour immediately above the transpiring surface are rapidly carried away and the rate of diffusion is accordingly increased, correspondingly the rate of transpiration is increased, but when the air movement is slow, the rate of diffusion is slow, consequently the rate of transpiration is also slow. Although any part of a plant exposed to the air may transpire, the leaves give off the most on account of their structure and position. To maintain turgor within the guard cells and other living tissues of the plant, the amount of water absorbed per unit of time should equal the amount transpired. When the rate of absorption of water is much less than the rate of transpiration, the living cells lose their turgor, the guard cells decrease in size, stomata close, and photosynthesis slows down or entirely stops (76). The experiments of other investigators showed that stomata opened in still air and closed in moving air (103). From a long time, there was a controversy as to whether the carbondioxide enters the leaf only through the stomata or also through the cuticle. It was decided by experiments that most of the gas exchange takes place through the stomata (245). The immediate effect of a water deficit within the plant is a reduction in CO_2 assimilation. This reduction in photosynthesis will correspondingly reduce growth and yield of the plant. There will be increase in transpiration per unit area of leaf surface as wind velocity increases. Such increases in transpiration will increase the diffusion pressure deficit in the leaves. WHITEHEAD (245) has reported leaf water deficit in wind. He found deficits of 8 or 12% in three species of *Senecio* after 11 hours in a wind speed of 4 m/sec and greater deficits at higher wind speeds. Deficits of this size will reduce photosynthesis both directly and by probable closure of the stomata. KUIPER (135) too pointed out that decrease in stomatal aperture with increase in wind velocity is often observed, especially at limited water supply of the shoot. KRAAIJENGA (131) in his experiments with the simultaneous use of growth graph and transpiration balances showed, that growth occurred when transpiration was slight and that the growth slowed down to a standstill as long as there was much transpiration. Of all the factors which regulate the transpiration, only the wind and the temperature can be influenced by means of shelterbelts.

Conclusions. The windbreak reduced the rate of transpiration by about 50% in its protected zone as compared to the non-protected zone in the wind tunnel. By reducing

Fig. 55. Mechanical damage of the wind on bean plants can be seen in the pot 16 HL in the unprotected zone. For comparison see bean plants in the pot 9 HR which were in the protected zone of the windbreak in the wind tunnel.

stages and also when it is at the milk stage could be bent and blown down by wind. The maize crop which is bent and blown down produces low yields. Some mature crops are also blown down by high winds and may suffer some loss in their yields. The mechanical damage is more intensive near the coast because the winds from sea are also saline in nature. In fields which are protected with a shelterbelt, the crop is insured against the mechanical damage of high winds.

Conclusions. The direct mechanical damage to the plants under the protection of the shelterbelt is reduced. Consequently the growth of the plants is not disturbed in the protected zone of the shelterbelt, whereas the plants in the unprotected zone suffer a setback in their growth from the direct mechanical damage as well as for their struggle for survival against the destructing high winds. Hence the protection provided against the mechanical damage of high winds to the plants is another major factor which is responsible for better development and higher yields of the crops in the protected zone of the shelterbelt.

5 – Photosynthetic surface

The author observed during his wind tunnel experiments and later in his field experiments that the numbers of leaves (see fig. 24 on p. 35) were higher and the size of the leaves bigger in the protected zone of the windbreak. The size of the leaves can be seen in fig. 56. The leaflets on the right side are from the windbreak protected zone and the left side leaflets are from the unprotected zone. It is quite evident from fig. 56 that the leaflets in the windbreak protected zone are much bigger as compared with the non-protected zone.

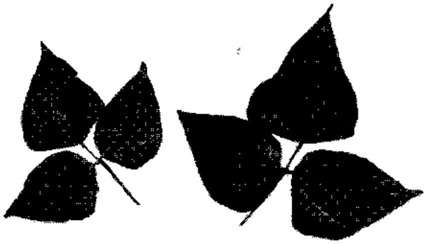


Fig. 56. The influence of the windbreak on the development of the photosynthetic area of bean crop. The leaflets on the right side are from the windbreak protected zone and the left side leaflets are from the unprotected zone. The leaflets are taken from corresponding nodes.

According to NICHIPROVICH (167) the following conditions are essential for the highest yield of the crop:

a. The best growth in leaf area;

b. the longest time for their function;

c. the higher rate of photosynthesis with the best distribution of the assimilantes formed, at first towards the formation of the nutrient organs and then towards the formation of the reproductive and storage organs which compose the main mass of the yield.

The author also noticed that the plant dimensions and the rate of their growth was related with the leaf area and number of leaves. Therefore, there is a correlation between the higher rate of growth with the increased photosynthetic surface.

Conclusions. The photosynthetic surface of the plants is increased under the protection of shelterbelts, consequently the plant can manufacture more carbohydrates which results towards a better growth and a higher yield of plants, whereas the growth of plants in the unprotected zone is left behind due to their smaller photosynthetic surface. Therefore, the increase in the photosynthetic surface of the plants is a direct effect of the major factors which were discussed before and which contributes for better development and higher yields of crops in the protected zone of the shelterbelts.

6 – ROOT/SHOOT RATIO

Forty-eight pots were made ready for the root/shoot ratio experiment in the wind tunnel at Wageningen. Each pot was filled with the same type of soil and treated with the same amount of fertilizer. Twenty-four pots were placed in the east side of the wind tunnel, 20 in the lee-section of the windbreak i.e. 1 H till 20 H, 4 in the windward-section of the windbreak i.e. 1 W till 4 W. Similarly, the other 24 pots were placed in the west side of the wind tunnel. Each pot was sunk into soil as was described in the previous chapter with pot experiments in the wind tunnel with bean and maize crops. Ten seeds of maize crop were sown in each pot. The seeds were allowed to germinate without wind treatment. When the seeds had germinated, the wind tunnel was operated on the same schedule as was used for the experiments of maize crop in the previous chapter. Ten days later, the thinning operation was carried out, only the best four maize plants were kept and the rest were thrown out. The plants were allowed to grow to the height of 60 cm in the protected zone of the windbreak, then the plants were harvested. Wet weight and dry weight of the above soil parts of the plants were recorded. The roots were also taken out of the soil by passing the soil through a sieve and then washing the roots. The wet weight and dry weight of roots were also recorded. The average results were calculated for the east and west sides of the wind tunnel for wet weight and dry weight of plants and roots respectively. From the average figures, the root/shoot ratio (R/S where R is the dry weight of roots and S is the dry weight of plants) was calculated, which is expressed in fig. 57.

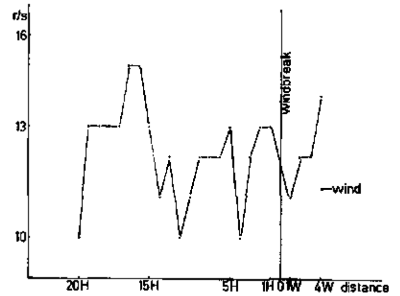


Fig. 57. The influence of the windbreak on the root and shoot ratio of maize crop in the wind tunnel at Wageningen.

Fig. 57 clearly shows that the root/shoot ratio is higher in the non-protected zone of the shelterbelt. The development of greater ratios of roots as compared to the shoots in the non-protected zone may be due to certain reasons. It may be due to the higher rate of evapo-transpiration in the non-protected zone of the shelterbelt, as a consequence of which the plant spends more of its manufactured carbohydrates on the development of roots, and thus hinders the growth of the shoot. The other factor which may also stimulate the growth of more roots in the plants as compared to the shoot in the non-protected zone of the shelterbelt may be the effect of continuous stress on the plants caused by wind.

Conclusions. The development of a lower amount of roots as compared to the shoots of the plant in the protected zone of the shelterbelt clearly indicates that the shoots and roots were growing in the optimal form. The plants in the unprotected zone were unable to keep their optimum growth due to wind and developed a relatively higher amount of roots, which would have not happened if these plants were in the wind protected zone. Hence the development of a lower amount of roots as compared with the shoot of the plants in the protected zone of the shelterbelt contributes to the better development and higher yield of crop.

7 – Summarizing conclusions.

The fundamental basis of all types of agriculture is the growth of plants. The agricultural practices can be only carried out successfully in conditions in which plant will grow. Most of the agricultural systems are not concerned with the plants that would grow under natural conditions, but with the crops that demand a considerable amount of time and attention from a farmer, who must provide them with conditions under which they will grow well and give high yield. The leaves of plants with favourable temperature, transpiration, and moisture condition, will develop more rows of pallisade cells and a greater number of chloroplasts within each cell, therefore these plants will make more carbohydrates per unit of time. Thus these plants will develop a greater shoot/root ratio which will result in a higher yield. Any increase in the temperature which leads towards the optimal temperature of plants results in more luxurious growth. High transpiration rates create the water deficit conditions which result in a lower rate of photosynthesis and as a consequence poor growth of plants. Favourable increase in the moisture conditions also leads to better growth and higher yield of crops. The shelterbelts increase the temperature, but simultaneously reduce the rate of transpiration, and conserve the soil moisture by reducing the rate of evaporation. These favourable changes result in the better growth and yield of crops in the protected zone of the shelterbelt. The shelterbelts protect the plants in their protected zone from the direct mechanical damage of wind, and the plants under protection grow luxuriously which consequently results in high yield of crops. The number of leaves and their photosynthetic surface are greater in the protected zone of the shelterbelt as compared with non-protected zone plants. The greater photosynthetic surface also contributes to the higher yield of crops in the protected zone of the shelterbelts. The plants also developed a lower amount of roots in comparison to the shoots in the protected zone of the shelterbelt. The plants in the non-protected zone of the shelterbelt developed a higher amount of roots in comparison to shoots, which may be due to water deficit conditions.

Hence the major factors influenced by the shelterbelt are temperature, transpiration, conservation of soil moisture, mechanical injury to plants, resulting in a larger photosynthetic surface and a better root/shoot ratio, which are mainly responsible for the better growth and the increase of the crop yields in the protected zone.

The author will bring forward the different aspects of the shelterbelts in part two of this publication. In that part, research is conducted for determining an optimal shelterbelt design. Also the phases of establishment and good management of shelterbelts are to be discussed which will lead to a better efficiency in providing protection from wind, and consequently it will lead to higher yield of the crops.

PART TWO - SHELTERBELTS

CHAPTER VI

ESTABLISHMENT OF SHELTERBELTS

The site, proper design and selection of species are the foundations on which the success of the establishment of a shelterbelt and the efficiency of its operation depend in future. Therefore, it is essential that a careful consideration is given to the various features of these three factors, with a view to provide optimal protection to the agricultural and horticultural crops for securing better growth and higher yields.

1 – SELECTION AND PREPARATION OF SITE

The original selection of the site for a shelterbelt is of great importance, inasmuch as the trees have to withstand adverse conditions over a long period. This means that where possible sufficient width should be provided for the trees to make their own shelter. The inner ones should be permitted to develop as naturally as possible, or an effort should be made to provide them with some degree of natural shelter (47). The latter may be accomplished by making the plantation complementary to some existing local feature, which already provides a measure of shelter. For example, it is normally a mistake to plant a shelterbelt along the ridge of a hill, or on a spur, where it will be subject to the most extreme wind forces. It is better to select a site just in the lee of a spur or a ridge. The trees will establish themselves more rapidly and vigorously in such a location and eventually will increase the uplift of wind which the natural feature already does to some extent.

STOECKLER and WILLIAMS (217) reported that the careful preparation of site is essential for the succesful establishment of a shelterbelt. Before any tree planting is done, the land should be in some cultivated crop, such as corn or potatoes, for at least one year (13). This will provide for the proper pulverizing of the soil and the killing of competing grasses and weeds. In addition, it will help to conserve moisture, usually the limiting factor in the growth of trees under dry land farming conditions (188).

2 – THE DESIGN OF SHELTERBELTS

2.1 – General. BATES (18), BEK (30), BURMISTROVS (42), CABORN (46), CADMAN (47), CAMPBELL (48), CHEYNEY (57), DENUYL (68), ERPERT (82), EVANS (84), EWSEJENKO (85), FADEER (86), GEORGE (94, 96), JOACHIM (122), KING (126), KLIMOV and KUSZJURIN (128,) KITIN (127), KOLDANOV (130), KRAEVOJ (133), LEONTIEVSKY (136), LUPE and CATRINA (142), NÄGELI (162), NAGLE and STUBBS (164), RAMSEY (177) and PANFILOV (173) emphasized the urgency for a good design of a shelterbelt which should provide maximum wind protection according to the local circumstances. The air-flow pattern due to a near-solid cross-wind barrier is given in fig. 58.

The design of a shelterbelt is highly important since it determines the extent to which the shelterbelt is effective in diffusing and diverting air currents. There are three principal factors in the designing of the shelterbelt which are height, density and length. Density is dependent on the width of shelterbelts, species composition, number of rows, spacing between rows and between trees. The tallest growing trees are placed in the center of the shelterbelt. The shorter growing trees are used along the sides and the shrubby growth on the edges. Evergreens can be used as shrubs near the edges because they retain their branches near the ground. They give greater assurance for the upward sweep of winds and provide protection during both winter and summer (94). Altogether, however, the hardwood trees appear better adapted in many local conditions than evergreen trees. Thus the total effect of tall and sheltering deciduous trees and shrubs with a combination of evergreens will create an effective barrier against the winds. The use of several species also affords insurance against any epidemic of disease or insects which may wipe out a given species. It also provides trees of different life spans so that the shelterbelt can be perpetuated indefinitely.

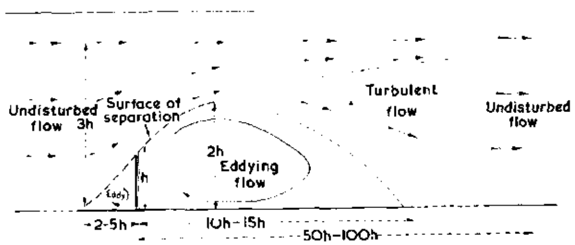


Fig. 58. Some characteristics of the air-flow pattern due to a near-solid cross-wind barrier (not to scale) (after Gloyne (199)).

The structure of the windbreak is dependent on its particular purpose, the wind velocity, and the species which are used in it. If it is established for the primary purpose of protecting buildings, livestock or poultry, it should be as compact as possible down to the surface of the ground (243). In such cases it may be advisable to plant a row or two of low trees or high and low shrubs along the outer margin of the trees either on one or both sides of the windbreak. Such a compact mass is not ideal, however, where an orchard field or garden crop is the object of protection. A limited amount of surface air drainage is desirable for these crops. Consequently the additional planting of shrubs or low trees can be left out.

A belt should normally be longer than the width of the area it is required to shelter, since wind will cut in around the ends. It is quite sound to turn the corners inwards though this needs extra fencing which is costly. It may be necessary to have fenced accesses for stock to pass through long belts. The openings in the shelterbelts may be left for roads, cattle lanes and other local purposes.

A properly designed shelterbelt gives reduction in wind velocity for a distance of 24 times the maximum height of the windbreak on the leeward side (255). A large field requires a windbreak system – a main belt on the windward sides and a number of supplemental belts. Shelterbelts should be located in a position where they will give protection from the prevailing winds. For example, if the prevailing winds are from the north and west, the shelterbelts should be placed on these sides of the fields or buildings to be protected. They should not be located too closely to farm buildings of public roads – not nearer than 33 m – because considerable snow will drift on the leeward side of the trees, the drift often extending 16 m beyond the windbreak (244).

Figures 59 and 60 show the results of the experiments in the U.S.A. for determining the influence of the shelterbelts on the wind velocity. The results show that the wind velocity was reduced up to the distance of 24 H.

Similar experiments for determining the reduction in wind velocity caused by the

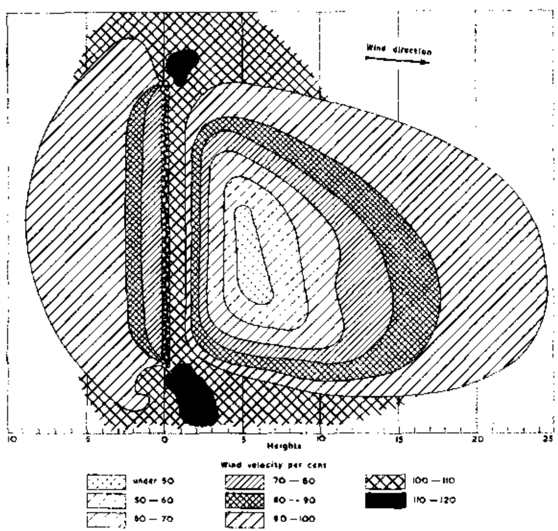


Fig. 59. Zone of wind velocity abatement near a windbreak of moderate penetrability (after Bates (22)).

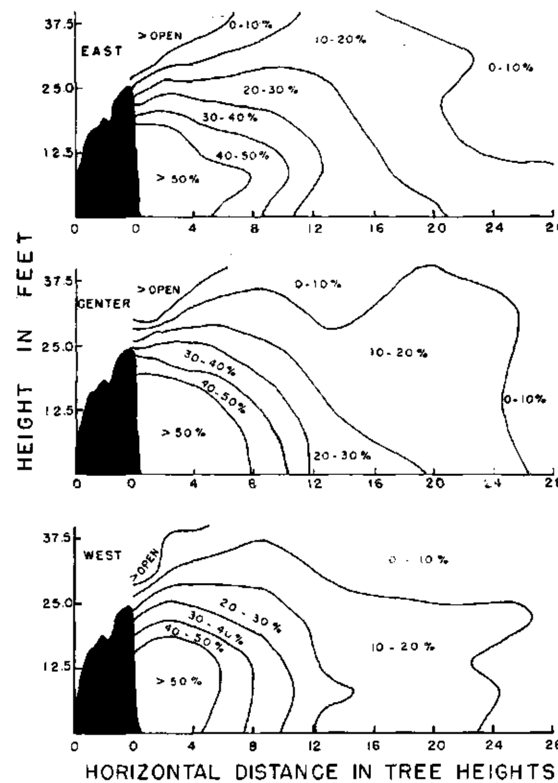


Fig. 60. Wind velocity reduction along the east, center and west sampling lines to the leeward of the shelterbelt. The shelterbelt was of 10-row, 16 years old, a 1/4-mile long, near Lyons, Kansas (255).

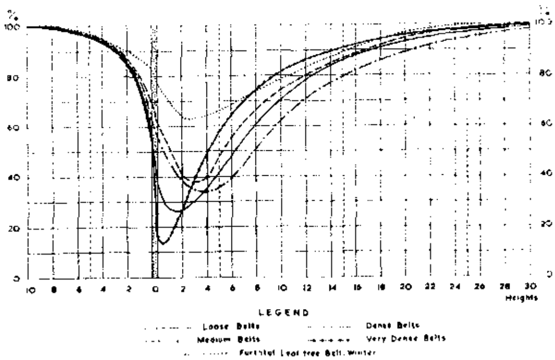


Fig. 61. Relative wind velocities in the vicinity of Swiss shelterbelts of different degrees of density (after Nägeli (161)).

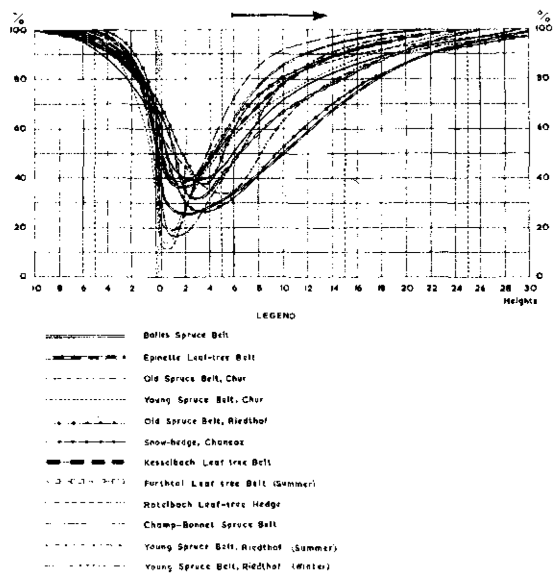
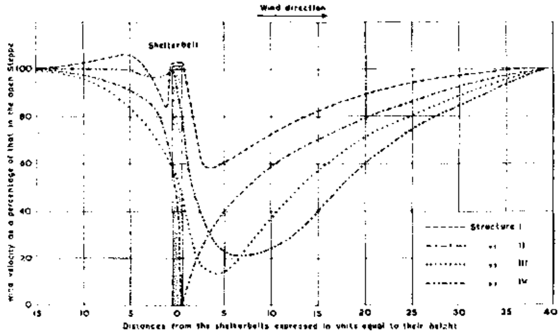


Fig. 62. Relative wind velocities in the vicinity of 12 shelterbelts (after Nägeli).

shelterbelts were done in Europe and the U.S.S.R. The results are given in the figures 61, 62 and 63 respectively. The results in these experiments also showed that the different shelterbelts depending on its density reduced the wind velocities with the various intensities up to the distance of at least 24 H.

The details in fig. 64 show the conditions of the wind in the vicinity of a gap in a shelterbelt. It clearly shows that the gap in the shelterbelt reduces the protective efficiency of the shelterbelt considerably.

2.2 – Methods of design employed in the U.S.A. Because of the widely differing conditions in the various areas of the Prairie Region, the designs of shelterbelts are not rigidly fixed, but vary according to the local circumstances. It is generally regarded important to plant a larger number of rows for farmstead, feedlot and main belts than for garden, orchard, and supplemental field belts. A minimum number of rows are used unless the site is very much exposed.



Structure I = shelterbelts open throughout their height (partly penetrable to wind).
Structure II = shelterbelts dense throughout their height (impenetrable to wind).
Structure III = shelterbelts of medium density (slightly permeable below, and dense above).
Structure IV = shelterbelts of medium density above, and open below.

Fig. 63. Relative wind velocities in the vicinity of Russian shelterbelts of different density (after Panfilov).

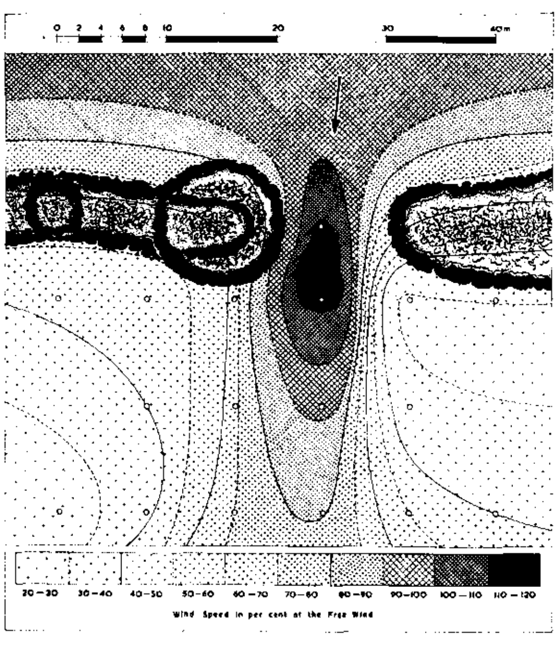


Fig. 64. Wind conditions in the vicinity of a gap in a shelterbelt (after Nägeli (162)).

The general plan of the shelterbelt design has not changed since 1935. But there has been some change in number of rows and spacing. In 1935 and 1936, the number of rows in a shelterbelt varied from 17 to 21, differing from south to north. The spacing varied by species and region. Primarily for administrative reasons, it was found highly desirable to use a uniform spacing and if possible to narrow the belt. Farmers in some sections felt that at the rate of approximately 20 acres for one mile of belt, too much land was being taken out from crop production. The width and spacing problem was carefully considered both from the administrative and the silvicultural points of view, and the present uniform standards were established. These standards, judging from available information, appear safe and avoid the extremes of both close and wide spacing.

In the Prairie States, shelterbelts were planted to meet the desires of the owner and the requirement dictated by the prevailing winds rather than in any predetermined geometric pattern. Consequently, most shelterbelts were located along property lines and usually in an east-west direction. They vary in length from 1/8 mile to a full mile, with occasional strips up to two miles in length as a result of continuous planting by owners along the same land line. The length of an individual shelterbelt is in most cases limited by farm size. Most farms have one shelterbelt, although a number of them have a second planted at right angles to the first for better protection.

The shelterbelts established in the U.S. Plains Region have two basic cross-section patterns. The earliest plantings were symmetrical, with the tallest growing tree in the centre flanked by shorter trees and tapering off to shrub rows on each side. The other pattern adopted after the project was well underway, was asymmetrical in cross-section with fewer rows.

2.3 – Spacing of the shelterbelt. NAGLE, STUBBS and JAMES (164) found that the effectiveness of a windbreak depends largely on the proper placement of the trees. At least three rows should be used and five or more are preferable. Broadleaf trees should be planted on the outside and evergreens on the inside. In the more exposed and drier areas it is advisable to plant the hardwoods two or three years in advance of evergreens, since the latter will have a better chance of surviving in the shelter of established trees. Rows should be three to four metres apart and trees two to three metres apart in the rows with the exception of the outside row which should be planted closely (one metre) to produce a dense hedgelike growth.

ANDERSON (13) and TRENK (228) reported that the tallest possible shelterbelt can be obtained only when at least one row of trees is subjected to shading. A single row or even two rows of trees will develop dense side limbs, but will not stimulate height growth. The centre row of a three-row shelterbelt will respond to competition from the side by sending up taller annual leaders. It is for this reason that wherever possible a shelterbelt should consist of three rows.

The study of GEORGE (96) showed that a shelterbelt cannot be fully effective in checking the wind and holding drifting snow until the branches of the trees have grown together. It is therefore necessary to adopt a system of spacing that will permit early branching together of the trees in the row but still leave sufficient space between rows for cultivation for the first few years. The spacing between rows, however, should be such that the crowns of the trees eventually will close in and thus shut out weed growth, prevent the entrance of sun and wind, thereby reducing evaporation and transpiration, and aid the development of forest conditions within the shelterbelt. Such conditions may result eventually in the suppression of individual trees. However, these trees can be removed without interfering with the desired crown cover or destroying the effectiveness of the shelterbelt.

The various spacing recommendations in published literature fall into three main groups. The first group of authorities suggest distances varying from 2 to 3 metres between rows and from 1.3 to 2.6 metres apart for trees in the row. These distances repeatedly permit the branches to meet sooner than wider spacings, thus allowing cultivation to be discontinued earlier. The second group recommends distances of 2.6 to 8 metres between rows and 2 to 2.6 metres for trees in the row. The principal reasons set forth to justify these comparatively wide spacings are that they permit the use of standard farm equipment for cultivation and lessen competition among the trees for soil moisture. The third group is comprised by the most recent recommendations for spacing given by the U.S. Department of Agriculture as set forth in Table 15.

Table 15 – RECOMMENDED SPACING DESIGN FOR SHELTERBELTS
SOURCE: GEORGE (94)

	metres
Between belts:	
main shelterbelt and first supplemental	166.6
other supplements	133.3 to 200.0
Between rows:	
two row shelterbelts	3.3
other shelterbelts	4.0 to 5.0
Between trees and shrubs:	
trees in leeward rows	2.0
trees in interior rows	2.0 to 2.6
shrubs	1.0

3 – SELECTION OF SPECIES

It must not be overlooked that various climatic factors, particularly wind, have a great influence on the shrub and tree species selected for shelterbelts. In some respects wind has a more serious effect on the trees than on the animals which they are intented to shelter sometimes, for livestock are mobile and can move according to the direction and force of the wind. The trees, on the other hand, are there for better or for worse, and as they grow in height, they become even more exposed. It is important, moreover, that a properly sited belt should be permanent. Since trees do not live forever, particularly under unfavourable conditions of severe exposure, it follows that some thought must be given at the outset to the ultimate means of regeneration.

The kind of trees to plant will depend largely on the soil and locality. In any event, it is a good plan to plant more than one species. This allows a combination of the advantages of each, and if one particular species should die, the effectiveness of the shelterbelt will not be completely lost.

Trees with a rather confined root system, developing but few large lateral roots and chiefly vertical or tap roots, and trees whose crowns are compact and tend more to vertical or short horizontal limb growth, are obviously the most desirable. Not only does the tree with a chiefly vertical root system do less sapping, but it is better anchored to withstand the severe winds to which it will necessarily be subjected.

When selecting trees primarily for shelterbelt purposes, the aesthetic features should not be overlooked. Most evergreens will easily satisfy this requirement. Moreover, evergreen trees are the foundation of the shelterbelt. Because they give year-round protection, grow more densely, and live longer than broadleaf species, they should be included in shelterbelts wherever possible. Evergreens are used in single row plantings, also as the inside row of multiple row plantings and for hedges of low windbreaks.

Among the broadleafs, the trees which develop a very symmetrical form are desirable for aesthetic purpose. Fast growing broadleafs should be mixed with evergreens wherever possible. They provide early protection and also assist in establishing the evergreens. Broadleafs are the tall trees in the shelterbelt and their height extends protection for great distances. In some areas certain broadleaf trees are the only ones that can be grown.

Ground winds are the worst winds. Therefore, a shelterbelt needs to be most dense at the ground level. Low, bushy shrubs should always be included as the outside row of a multiple row planting. In many areas shrub rows are necessary to give protection to evergreen plantings in order to help them to get established.

It is advisable to choose those species which are grown locally. But the other species known to be hardy in other localities can also be used.

4 – Conclusions

It is important for the establishment of shelterbelts that a very careful selection of species, site and design should be carried out, but the above review of literature presents different aspects of shelterbelt designs. The existing studies does not give clearly the information how various shelterbelts will react in providing protection from wind if their basic designs are different from one another, e.g. some shelterbelts may have streamline structures with various degrees of slopes, while others may break the force of the wind as a straight standing structure. Neither do these studies provide any detailed information how the shelterbelts with different air drainages will respond in providing protection from wind. Therefore, the author conducted a series of experiments with the aid of various shelterbelt design models in the wind tunnel for finding the answers to the above mentioned problems. The details of the experiments for determining the optimum designs for the shelterbelts are given in the next chapter.

Chapter VII

DETERMINING THE OPTIMUM SHELTERBELT DESIGN

There was no clear concept on the protective efficiency rates of various types of shelterbelts. There are controversial statements. Therefore, a research was started for finding the possible protective efficiencies by means of models of various types of shelterbelt design in the wind tunnel. Certainly this approach has its limitations. But this method may furnish some relationship between different kinds of shelter designs.

The author conducted the shelterbelt design models experiments in the wind tunnel of the Institute for Soil Fertility (Instituut voor Bodemvruchtbaarheid) at Groningen. The main objective of this institute is to study problems of soil fertility. For reaching the above mentioned goal, the institute is equipped with laboratories and the work is also carried out in experimental plots. Its research is carried out in collaboration of horticulturists, soil scientists, biologists, chemists and physicists.

1 – Method and technics

The wind tunnel used for investigating the protective efficiencies of various types of shelterbelt models is of the Eifel type (suction type, fan leeward of the research section). The air enters the tunnel through a honeycomb (125 × 180 cm^2) of 10,000 plastic tubes (long 10 cm, ⌀ 1.5 cm), mounted in the wall of the building. This system prevents the entrance of big eddies in the tunnel. A metal funnel is connecting the honeycomb with the part of the tunnel in which the experiments are done. This part has a square cross section (75 × 75 cm^2), a bottom and roof of wooden board and sidewalls consisting of glass windows, which are removable. The length of the research section is 10 m. At its lee-side, it is connected with a big soil settling box (2.2 × 1.5 × 2.5 m). The air stream is further passing an adjustable screen, regulating the wind velocity (together with the speed of the driving diesel engine) and the fan respectively and is leaving the apparatus by a funnel on the roof of the building. Different wind velocities could be realized up to the maximum of 20 m per second. In fig. 65, the front part of the wind tunnel is shown.

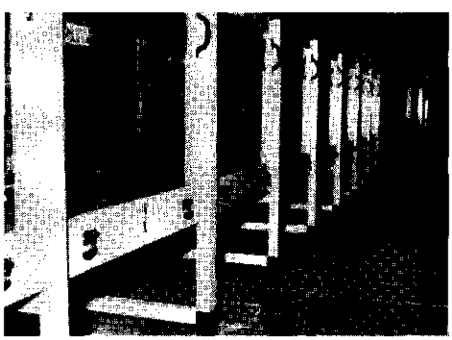


Fig. 65. The front part of the wind tunnel at Groningen.

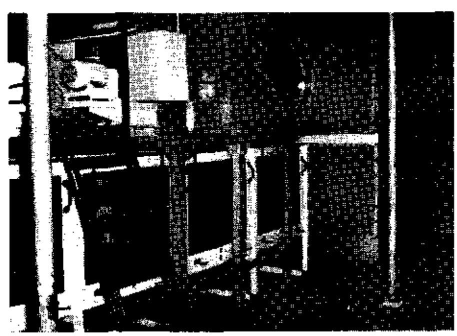


Fig. 66. The rear end of the wind tunnel at Groningen.

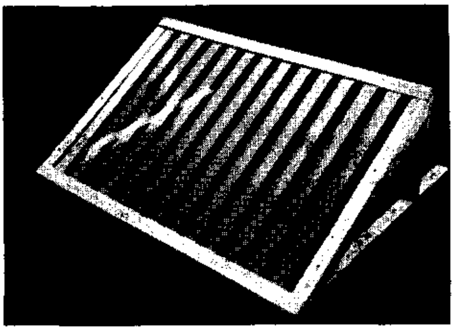


Fig. 67. The shelterbelt model Shamim type.

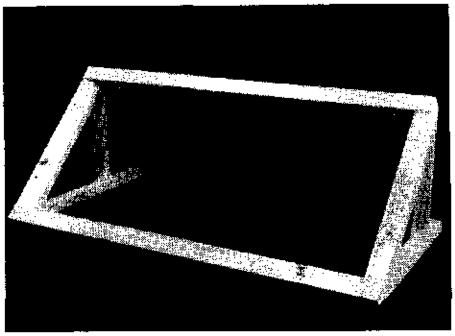


Fig. 68. The shelterbelt model Khalid type.

The removable glass windows can also be seen. Fig. 66 shows the rear end of the wind tunnel. Glass windows connecting with the big soil settling box can be seen. Above the glass windows can be seen the diesel engine which operates the wind tunnel.

The shelterbelt models were designed by the author and were constructed in the workshop of the Institute for Biological Field Research (Itbon) at Arnhem. The total height and breadth of all the models are the same, namely 28 cm and 75 cm respectively. All were constructed on wooden frames. The front part which is facing the wind was covered with plastic strips which were running longitudinally so that there was 40% of air drainage. But in other details each model differed from another. In fig. 67 the shelterbelt model type Shamim can be seen. (For a comparison of the different models see also Tables 16 or 17 on p. 73.)

This model is facing the coming wind at the angle of 30°. The total length of the slope of this model on which the wind velocity will be facing resistance is 51 cm. Thus, the shelterbelt model Shamim type breaks the force of the wind as a windbreak and also provides a streamline structure which assists in further slowing down the wind velocity. This model may be compared to a ten row-shelterbelt.

In fig. 68, the shelterbelt model Khalid type can be seen. This model differs from the Shamin type in slope and in angle by which it is facing the wind. Khalid type model is facing the coming wind at an angle of 45°. The total length of the slope of this model on which the wind velocity will be facing resistance is 36.2 cm. This model may be compared to a six to eight row-shelterbelt.

In fig. 69, the shelterbelt model Ikram type can be seen. This model is facing the coming wind at the angle of 60° and the total length of the slope which the wind velocity will be facing is 29 cm. This model may be compared to a three to five row-shelterbelt.

The shelterbelt model Usman type can be seen in fig. 70. This model differs from all the other models because it has no stream-line slope and it faces the coming wind at the angle of 90°. This shelterbelt model may be compared with an one to three row-windbreak.

In fig. 71, the shelterbelt model Rana type can be seen. This model is completely similar to the shelterbelt model Khalid type except that in this case the lower 25% of the model is completely covered with a wooden board. Thus in this model the lower part has no air drainage. This model may be compared to a six to eight row-shelterbelt with a dense under-storey of shrubs up to the 25% height of the shelterbelt trees.

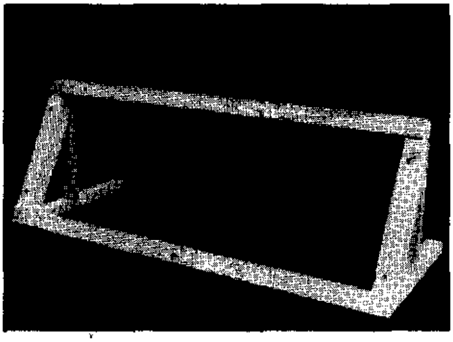


Fig. 69. The shelterbelt model Ikram type.

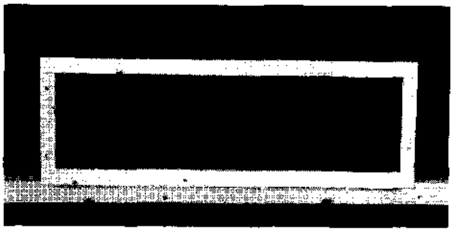


Fig. 70. The shelterbelt model Usman type.

The shelterbelt model Ali type can be seen in fig. 72. This model is similar to the shelterbelt model Usman type except that in this case the lower 25% of the model is completely covered with a wooden board. This model may be compared to a one to three row-windbreak with a dense under-storey of shrubs up to the 25% height of the shelterbelt trees.

For determining the optimum density (or spacing of the trees in rows), the author also conducted a series of experiments in the wind tunnel. For this purpose the shelterbelt design model Usman type was selected. A set of this type with various air drainages was made. This was done by changing the size of the breadth of plastic strips which were running longitudinally in the front part of the model. The air drainages were 0% (which was a solid wall), 10%, 20%, 30%, 40%, 50%, 60%, and 70% respectively.

For determining the relative humidity, the author used an aspirations psychrometer which can be seen in fig. 73.

It consists of two thermometers, one covered with cotton wool and the other one free. The bottom parts of the thermometers are covered with metalic tubes which are connected at the top of the ventilator. The cotton wool is made wet by means of a dropper. The ventilator is wound up by means of a key. Then the ventilator starts operating which sucks the air from the metalic tubes in which the bottom parts of the thermometer are placed. As a consequence of evaporation, different readings are recorded at the wet and

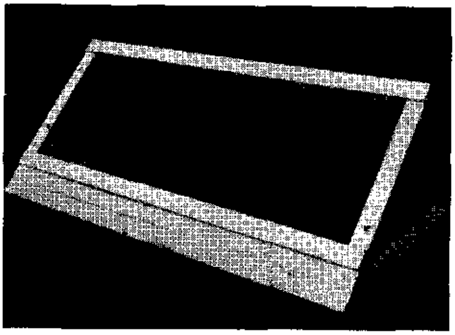


Fig. 71. The shelterbelt model Rana type.

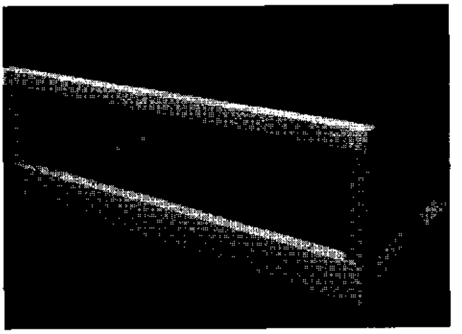


Fig. 72. The shelterbelt model Ali type.

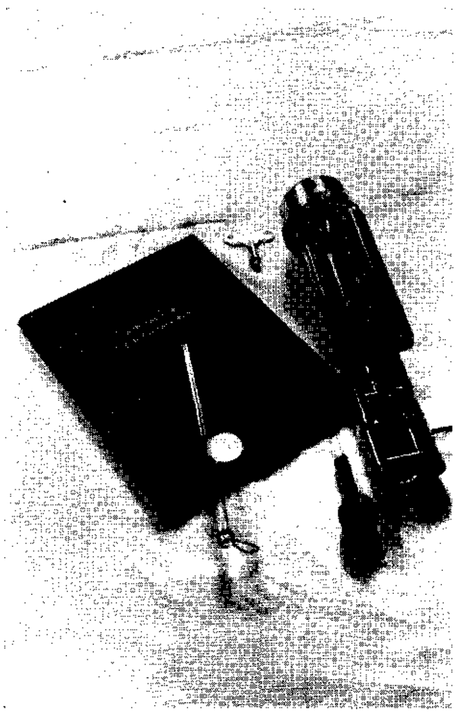


Fig. 73. The aspiration psychrometer with the winding key and dropper. On 'Aspiration Psychrometer-Tafeln' is the Piche evaporimeter with a round filter paper.

dry thermometers. The observations are taken when the reading in the thermometers reaches the lowest point. The wet and dry thermometer readings indicate directly the relative humidity of the air by using the aspirations psychrometer tables.

In order to determine some kind of relationship between the models, the author gave three different types of treatments to all the shelterbelt design models for finding out their protective value. The three treatments were the wind velocity, the rate of evaporation, and the amount of sand erosion respectively. It turned out that the models did react differently from each other. The observations and results from each treatment are discussed below in details.

2 – Wind velocity treatment

Each type of the shelterbelt model was exposed to moderate wind, hard wind and stormy wind respectively. These treatments were given so as to determine to what extent each model reduces the wind velocity in its lee-side. In order to determine the wind velocity directly in the wind tunnel, Pitot-tubes connected with low sloping oil manometers were used. Seven Pitot-tubes and the seven oil manometers which were used in these experiments can be seen in fig. 74 and fig. 75 respectively.

The Pitot-tubes give the measurements of the static pressure and total pressure which could be read directly from the oil manometers simultaneously. When the static pressure and the total pressure were known, the following formula was used to calculate the wind velocity:

$$W = \frac{2}{p} \quad (Pt - Ps),$$

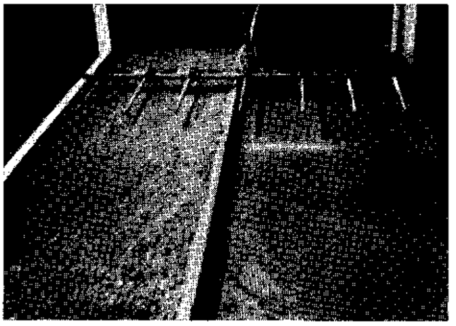


Fig. 74. Seven Pitot-tubes used in the wind tunnel at Groningen.

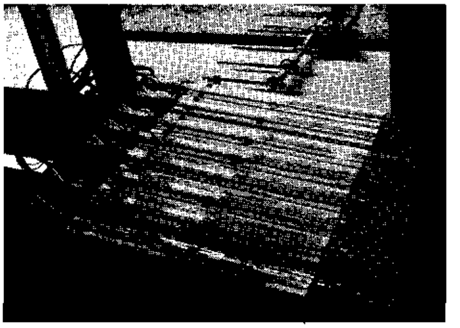


Fig. 75. Seven low sloping oil manometers used in the wind tunnel at Groningen.

where W is the wind velocity, p is density of air, P_t is the total pressure and P_s is the static pressure.

The Pitot-tubes were placed at various distances in the lee-section of the models during the period of conduction of experiments. The manometers were placed outside the tunnel, but were connected by means of rubber tubes with the Pitot-tubes. The first experiment was started with moderate wind. The wind velocity without any model was recorded at the various sections of the wind tunnel.

Then the model Shamin type was placed in the tunnel and the wind velocities were recorded at various distances in the lee-section of the model. Similarly the wind velocities in the lee-section of model Khalid type, model Ikram type, model Usman type, model Rana type and model Ali type were recorded. Experiments were repeated with hard and stormy winds.

For determining the influence of the various air drainages in the shelterbelt models, the author gave all the models two treatments, that was of moderate and hard wind.

Discussion of results. The influence of various types of shelterbelt models on the wind velocity under the treatment of moderate wind is clearly indicated in Table 16.

The shelterbelt model Shamim type reduced the wind velocity at least up to 30 H_L. (1 H_L=75 cm, which is the height of all the models.)

The shelterbelt model Khalid type reduced the wind velocity up to 25 H_L, and the remaining models reduce the wind velocity up to 20 H_L. There is no doubt that all the models did reduce the wind velocity up to 30 H_L when treated with moderate wind, though they were less effective except the Shamim type and Khalid type shelterbelt design models. But up to the distance of 10 H_L, the protective efficiency of all the shelterbelt design models in reducing the wind velocity was superior to the shelterbelt model Shamim type.

After the moderate wind treatment, all the models were subjected to the hard and stormy winds. Tables 17 and 18 give the details of the observations.

The major reason for these treatments was to find out whether they reacted towards high winds in the same or in a different manner. When all the models were exposed to hard and stormy winds, the shelterbelt models type Rana and Ali were best, followed by the Shamim type in providing protection for the greater areas i.e. in this case up to

Table 16 – THE INFLUENCE OF THE VARIOUS TYPES OF SHELTERBELT MODELS ON THE MODERATE WIND IN THE WIND TUNNEL

MODEL		Wind velocities at the different distances in m/sec Protective efficiencies in % (in parenthesis)					
		5 H_L	10 H_L	15 H_L	20 H_L	25 H_L	30 H_L
Free wind		6.1 (0%)	5.8 (0%)	5.9 (0%)	5.7 (0%)	5.7 (0%)	5.8 (0%)
Shamim type		2.9 (52%)	2.7 (53%)	2.7 (54%)	3.3 (43%)	3.8 (33%)	4.3 (25%)
Khalid type		1.6 (73%)	1.9 (67%)	2.7 (54%)	3.7 (35%)	4.3 (24%)	4.7 (18%)
Ikram type		0.0 (100%)	1.9 (67%)	3.1 (47%)	4.1 (28%)	4.7 (17%)	4.9 (17%)
Usman type		0.0 (100%)	0.0 (100%)	2.7 (54%)	4.0 (29%)	4.6 (19%)	4.9 (17%)
Rana type		1.1 (81%)	1.9 (67%)	3.5 (40%)	4.6 (19%)	4.7 (17%)	4.9 (17%)
Ali type		0.0 (100%)	0.0 (100%)	3.5 (40%)	4.8 (15%)	5.2 (8%)	5.5 (5%)

Table 17 – THE INFLUENCE OF THE VARIOUS TYPES OF SHELTERBELT MODELS ON THE HARD WIND IN THE WIND TUNNEL

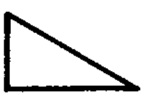
MODEL		Wind velocities at the different distances in m/sec Protectieve efficiencies in % (in parenthesis)					
		5 H_L	10 H_L	15 H_L	20 H_L	25 H_L	30 H_L
Free wind		9.8 (0%)	9.2 (0%)	9.4 (0%)	9.4 (0%)	9.2 (0%)	8.9 (0%)
Shamim type		5.0 (48%)	4.6 (50%)	4.8 (48%)	5.3 (43%)	6.0 (35%)	6.7 (24%)
Khalid type		2.5 (74%)	2.7 (70%)	4.4 (53%)	6.0 (36%)	6.7 (27%)	7.3 (17%)
Ikram type		1.1 (88%)	2.7 (70%)	4.8 (48%)	6.5 (30%)	7.1 (22%)	7.5 (15%)
Usman type		0.0 (100%)	2.7 (70%)	4.4 (53%)	6.3 (32%)	6.7 (27%)	7.3 (17%)
Rana type		1.1 (88%)	1.9 (79%)	3.5 (62%)	4.6 (51%)	4.7 (48%)	4.9 (44%)
Ali type		0.0 (100%)	0.0 (100%)	3.5 (62%)	4.8 (48%)	5.2 (43%)	5.5 (38%)

Table 18 – THE INFLUENCE OF THE VARIOUS TYPES OF SHELTERBELT MODELS ON THE STORMY WIND IN THE WIND TUNNEL

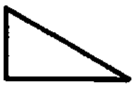
MODEL	Wind velocities at the different distances in m/sec Protective efficiencies in % (in parenthesis)					
	5 H_L	10 H_L	15 H_L	20 H_L	25 H_L	30 H_L
Free wind	16.8 (0%)	16.5 (0%)	16.2 (0%)	17.0 (0%)	17.0 (0%)	17.1 (0%)
Shamim type 	10.3 (38%)	9.0 (45%)	8.6 (46%)	10.2 (40%)	10.9 (35%)	12.7 (25%)
Khalid type 	6.0 (64%)	5.3 (67%)	8.3 (48%)	11.7 (31%)	12.5 (26%)	13.0 (23%)
Ikram type 	3.3 (80%)	4.8 (70%)	8.9 (45%)	11.0 (35%)	13.3 (21%)	14.6 (14%)
Usman type 	0.0 (100%)	4.8 (70%)	7.7 (52%)	12.7 (25%)	12.3 (27%)	14.2 (16%)

Table 19 – THE INFLUENCE OF THE USMAN TYPE SHELTERBELT MODEL WITH VARIOUS AIR DRAINAGES ON THE MODERATE WIND IN THE WIND TUNNEL

MODEL	Wind velocities at the different distances in m/sec Protective efficiencies in % (in parenthesis)						
	1 H_L	5 H_L	10 H_L	15 H_L	20 H_L	25 H_L	30 H_L
Free wind	6.2 (0%)	6.1 (0%)	5.8 (0%)	5.9 (0%)	5.7 (0%)	5.7 (0%)	5.8 (0%)
0% (Solid wall)	0 (100%)	0 (100%)	0 (100%)	4.4 (25%)	5.4 (5%)	5.9 (0%)	5.9 (0%)
10%	0 (100%)	0 (100%)	0 (100%)	3.5 (40%)	5.0 (12%)	5.6 (1%)	5.8 (0%)
20%	0 (100%)	0 (100%)	0 (100%)	3.5 (40%)	4.9 (14%)	5.4 (5%)	5.6 (3%)
30%	0 (100%)	0 (100%)	1.6 (72%)	3.1 (47%)	4.4 (22%)	5.2 (8%)	5.7 (1%)
40%	0 (100%)	0 (100%)	0 (100%)	2.7 (54%)	4.0 (29%)	4.6 (19%)	4.9 (15%)
50%	0 (100%)	1.1 (81%)	1.1 (81%)	3.1 (47%)	3.8 (33%)	4.3 (24%)	4.7 (18%)
60%	0 (100%)	2.2 (63%)	2.2 (62%)	2.7 (54%)	4.0 (29%)	4.0 (29%)	4.7 (18%)
70%	0 (100%)	3.1 (49%)	3.5 (39%)	3.5 (40%)	3.8 (33%)	4.0 (29%)	4.3 (25%)

Table 20 – THE INFLUENCE OF THE USMAN TYPE SHELTERBELT MODEL WITH VARIOUS AIR DRAINAGES ON THE HARD WIND IN THE WIND TUNNEL

MODEL	Wind velocities at the different distances in m/sec Protective efficiencies in % (in parenthesis)						
	1 H_L	5 H_L	10 H_L	15 H_L	20 H_L	25 H_L	30 H_L
Free wind	9.0 (0%)	9.7 (0%)	9.6 (0%)	9.4 (0%)	9.4 (0%)	9.2 (0%)	9.1 (0%)
0% (Solid wall)	0 (100%)	0 (100%)	1.6 (83%)	6.3 (32%)	8.3 (10%)	8.8 (4%)	9.1 (0%)
10%	0 (100%)	0 (100%)	0 (100%)	5.4 (42%)	7.2 (23%)	8.6 (6%)	8.8 (3%)
20%	0 (100%)	0 (100%)	1.1 (88%)	5.5 (42%)	6.9 (26%)	8.5 (7%)	8.8 (3%)
30%	0 (100%)	0 (100%)	2.7 (71%)	5.2 (44%)	6.9 (26%)	7.7 (16%)	8.6 (5%)
40%	0 (100%)	0 (100%)	2.7 (71%)	4.4 (53%)	6.3 (32%)	6.7 (27%)	7.3 (19%)
50%	0 (100%)	2.5 (74%)	2.5 (73%)	4.1 (56%)	6.1 (35%)	6.7 (27%)	7.2 (20%)
60%	0 (100%)	3.8 (60%)	3.8 (56%)	4.6 (51%)	5.9 (37%)	6.6 (28%)	7.1 (21%)
70%	0 (100%)	5.2 (46%)	5.3 (44%)	5.3 (43%)	5.9 (37%)	6.3 (31%)	6.9 (24%)

30 H_L. The shelterbelt model Ali type also proved to be best in protecting small areas and the shelterbelt model Usman type proved to be the next best one for the same purpose.

The various air drainage models were exposed to moderate and hard winds. The details of the results are given in Tables 19 and 20 respectively.

Under the treatment of moderate wind, 40% air drainage proved to be best up to 15 H_L. But at 20 H_L the lead was taken by 50% air drainage model. At the distance of 25 H_L and 30 H_L, 60% and 70% air drainage models proved to be the best. When the air drainage models were exposed to the hard wind, up to the distance of 15 H_L the 50% air drainage model proved to be the best. But at the distance of 20 H_L, the 60% air drainage model took over the lead. Later at the distances of 25 H_L and 30 H_L, 70% air drainage model proved to be the best in providing the protection from high winds.

Conclusions. The shelterbelt model Shamim type proved to be the best design for constructing shelterbelts when large areas are to be protected against moderate and stormy winds. The shelterbelt model Usman type proved to be the best design for constructing shelterbelts when small areas are to be protected against moderate and stormy winds. For protecting large and small areas from the hard wind, Ali type shelterbelt model was the best. The protective efficiency of each model was reduced when treated with higher wind velocities.

The optimum air drainage for the density of shelterbelts was found to be between 40% and 50%, if the area to be protected is small. But when the area which is to be protected is large, the air drainage should be between 60% and 70% for securing maximum protection from the shelterbelt.

3 – Evaporation measurements

The evaporation experiments were conducted with a view to determine the influence of each type of the shelterbelt design models as well as of the various air drainage models on the amount of evaporation in the lee-section of their area which was protected from wind. For this a Piche evaporimeter was used. It consists of a calibrated tube and can hold 20 ml of water. (The Piche evaporimeter with a round filter paper can be seen in fig. 73 on p. 71). The diameter of the tube is 1.4 cm and the total length is 25.0 cm. A steel clip is fixed to the bottom of the tube in which a round filter paper can be fixed so that the evaporation can take place. The diameter of the filter paper which was used by the author in his evaporation experiments, was 3.5 cm and the total area of the surface for evaporation of the filter paper was 19.2 cm^2. But the actual free surface of the filter paper for evaporation was 17.7 cm^2 after subtracting the surface of the filter paper which came under the clip of the evaporimeter tube.

About three quart of all the evaporimeters which were used in the experiment were filled with water and then the round filter paper was inserted in the clip. A hole was made in each filter paper with a fine needle before inserting the filter paper in the clip of the evaporimeter.

Seven evaporimeters fixed with the round filter paper and water were placed in the wind tunnel at distances of 1 H_L, 5 H_L, 10 H_L, 15 H_L, 20 H_L 25 H_L, and 30 H_L respectively from the shelterbelt model. The evaporimeters were hung at the distance of 4.7 cm from the floor of the wind tunnel by means of a string.

Four of the shelterbelt design models were treated with moderate wind. The wind velocity was 6 m per second. The initial readings were recorded from the evaporimeter tube before the wind treatment was given. After two and a half hours, the final reading was recorded. The difference between the initial and the final readings gave the amount of water evaporated. The relative humidity was also determined by means of an aspirations psychrometer before the initial reading and after the final reading of the evaporimeter tube.

The influence of four types of shelterbelt design models on the total amount of evaporation in the evaporimeters placed at the various distances was determined, and the details of the results are given in Table 21. Similarly the Usman type shelterbelt model with the various air drainages was used for determining their influence on the total amount of evaporation of water from the evaporimeters placed at the different distances from the shelterbelt models.

Discussion of results. The details of the results are given in Tables 21 and 22 respectively.

Table 21 – THE INFLUENCE OF THE VARIOUS TYPES OF SHELTERBELT MODELS ON THE EVAPORATION IN THE WIND TUNNEL

MODEL		Amount of water evaporated at the different distances (in ml)							Relative Humidity
		$1\,H_L$	$5\,H_L$	$10\,H_L$	$15\,H_L$	$20\,H_L$	$25\,H_L$	$30\,H_L$	
Shamim type		0.33	0.30	0.30	0.30	0.30	0.32	0.37	88%
Khalid type		0.65	0.58	0.48	0.61	0.66	0.73	0.72	75%
Ikram type		0.50	0.20	0.40	0.40	1.00	1.20	1.20	74%
Usman type		0.20	0.20	0.20	0.20	0.32	0.46	0.42	90%

Table 22 – THE INFLUENCE OF THE USMAN TYPE SHELTERBELT MODEL WITH VARIOUS AIR DRAINAGES ON THE EVAPORATION IN THE WIND TUNNEL

MODEL	Amount of water evaporated at the different distances (in ml)							Relative Humidity
	$1\,H_L$	$5\,H_L$	$10\,H_L$	$15\,H_L$	$20\,H_L$	$25\,H_L$	$30\,H_L$	
0% (Solid wall)	0.37	0.49	0.41	0.48	0.50	0.57	0.59	83%
10%	0.29	0.36	0.38	0.44	0.43	0.52	0.50	84%
20%	0.27	0.29	0.28	0.26	0.39	0.38	0.40	85%
30%	0.18	0.16	0.17	0.23	0.26	0.24	0.26	90%
40%	0.20	0.20	0.20	0.20	0.32	0.46	0.42	91%
50%	0.11	0.08	0.11	0.14	0.18	0.16	0.16	92%
60%	0.34	0.32	0.35	0.36	0.36	0.40	0.43	87%
70%	0.31	0.28	0.32	0.35	0.36	0.37	0.42	86%

The evaporation was least under the protection of the shelterbelt model Usman type up to the distance of 15 H_L. From the distance of 20 H_L till 30 H_L, the evaporation was the lowest under the protection of the shelterbelt model Shamim type.

The evaporation was minimal when the air drainage through the shelterbelt model was 50%, but under the protection of the solid wall the evaporation was maximum at all distances.

The evaporation method proved not to be a perfect one. There were some disadvantages with this method. The first was the weather which never stayed the same every day. The other disadvantage was that the machine which operated the ventilator created some vibrations in the wind tunnel, causing some motion in the evaporimeters which were hanging by means of strings. Also, the evaporimeters themselves created some turbulance in the air.

Conclusions. The Shamim type shelterbelt model proved to be the best in protecting against evaporation over a larger area. For smaller areas, the Usman type shelterbelt model provided the maximum protection to minimize the evaporation.

The optimum air drainage for the shelterbelt models proved to be 50%.

4 – Sand treatment

A series of experiments was started on the influence in reducing the wind erosion by the various types of shelterbelt design models, so that the protective efficiency rate of each model could be found. The details of the experiments are as follows:

The area of 3.57 H_L in the lee-section of the shelterbelt design models was kept free from sand under the assumption based on the author's other experiments that the above mentioned area was protected by all the models. The differences in their protective efficiencies arise at further distances from the shelterbelt models.

At the distance of 3.57 H_L the first plate with sand was placed, followed by five more similar plates. So in total there were six plates placed in the lee-side of the shelterbelt model. The length of each plate was 122 cm, the breadth was 35 cm, and the depth was 2 cm. These plates were made of wood and were placed in the centre of the wind tunnel.

The type of the sand used for this experiment was the dune sand, especially found in the bulb growing areas. The humidity of the dry air sand was 0.2%. The pH (in H_2O) was 8.9 and pH (in KC1) was 8.7.

An analysis* of the size of the sand particles is as follows:

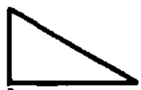
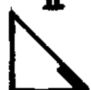
< 16 μ	:	1.1%
16— 50 μ	:	1.5%
50— 75 μ	:	0.7%
75—105 μ	:	1.1%
105—150 μ	:	10.2%
150—210 μ	:	41.2%
210—300 μ	:	32.7%
300—420 μ	:	5.8%
420—600 μ	:	0.3%

*A few rough particles of organic matter were sieved out.
μ is 1/1000 mm.

Each plate was weighed with the sand and placed in the tunnel. The relative humidity was recorded. Then the wind was blown in the tunnel for five minutes only. After stopping the wind, each of the six plates was weighed again. The difference between the initial and final weighing gave the amount of sand eroded. All the plates were placed again at their old positions without any fresh addition of sand, and the wind was blown for another five minutes. After stopping the wind, each of the six plates was weighed again and this weighing was recorded as final II reading. The difference between the final and final II readings gave the amount of sand eroded in the second five minutes wind treatment. This process was repeated with each type of the shelterbelt design model.

Discussion of results. The influence of the various types of shelterbelt design models on the erosion of the sand in the wind tunnel is given in Table 23.

Table 23 – THE INFLUENCE OF THE VARIOUS TYPES OF SHELTERBELT MODELS ON THE EROSION OF THE SAND IN THE WIND TUNNEL WHEN THE WIND WAS BLOWN FOR 10 MINUTES

MODEL		Amount of sand eroded at the different distances (in g) Protective efficiencies in % (in parenthesis)						Relative Humidity
		3.57 H_L till 7.92 H_L	7.93 H_L till 12.27 H_L	12.28 H_L till 16.62 H_L	16.63 H_L till 20.97 H_L	20.98 H_L till 25.32 H_L	25.33 H_L till 29.67 H_L	
Free wind		1255 (0%)	1875 (0%)	1150 (0%)	900 (0%)	605 (0%)	1415 (0%)	70%
Shamim type		5 (99%)	5 (99%)	15 (98%)	75 (91%)	320 (47%)	920 (35%)	70%
Khalid type		0 (100%)	5 (99%)	10 (99%)	60 (93%)	530 (12%)	1275 (14%)	75%
Ikram type		15 (99%)	0 (100%)	85 (92%)	895 (0%)	1660 (0%)	2050 (0%)	56%
Usman type		5 (99%)	5 (99%)	15 (98%)	160 (82%)	905 (0%)	1855 (0%)	70%
Rana type		5 (99%)	15 (99%)	25 (97%)	320 (64%)	1215 (0%)	1835 (0%)	67%
Ali type		0 (100%)	5 (99%)	60 (94%)	470 (47%)	905 (0%)	2515 (0%)	67%

All the shelterbelt design models provided more than 90% of protection to the sand from erosion up to the distance of 16.62 H_L. The shelterbelt models Khalid type, Shamim type and Usman type proved respectively to be the best in providing protection from erosion to the distance of 20.97 H_L. Beyond the above mentioned distance and up to 29.67 H_L, only the shelterbelt model Shamim type provided an appreciable protection. The influence of the Usman type shelterbelt model with various air drainages on the erosion of the sand is given in Table 24.

The minimum wind erosion took place under the protection of the shelterbelt design models with 70% and 60% air drainage respectively up to the distance of 29.67 H_L. The shelterbelt models with 50% and 40% air drainage reduced the wind erosion effectively up to the distances of 25.32 H_L and 20.97 H_L respectively. The shelterbelt models with 30% and 20% air drainage were effective only up to the distance of 16.62 H_L. The shelterbelt with the solid wall proved to be of no practical value in providing protection from wind erosion.

Table 24 – THE INFLUENCE OF THE USMAN TYPE SHELTERBELT MODEL WITH VARIOUS AIR DRAINAGES ON THE EROSION OF THE SAND IN THE WIND TUNNEL WHEN THE WIND WAS BLOWN FOR 10 MINUTES

MODEL	Amount of sand eroded at the different distances (in g) Protective efficiencies in % (in parenthesis)						Relative Humidity
	$3.57 H_L$ till $7.92 H_L$	$7.93 H_L$ till $12.27 H_L$	$12.28 H_L$ till $16.62 H_L$	$16.63 H_L$ till $20.97 H_L$	$20.98 H_L$ till $25.32 H_L$	$25.33 H_L$ till $29.67 H_L$	
Free wind	1405 (0%)	2285 (0%)	1160 (0%)	770 (0%)	980 (0%)	1000 (0%)	87%
0% (Solid wall)	2100 (0%)	175 (90%)	1060 (8%)	2845 (0%)	3190 (0%)	2335 (0%)	87%
10%	215 (84%)	85 (96%)	415 (64%)	1820 (0%)	3075 (0%)	2790 (0%)	87%
20%	20 (98%)	50 (97%)	205 (84%)	1485 (0%)	2405 (0%)	2925 (0%)	87%
30%	5 (99%)	25 (99%)	155 (88%)	1190 (0%)	2265 (0%)	3000 (0%)	77%
40%	5 (99%)	5 (99%)	15 (99%)	160 (79%)	905 (7%)	2515 (0%)	70%
50%	10 (99%)	15 (99%)	25 (98%)	35 (95%)	175 (82%)	980 (2%)	77%
60	15 (98%)	20 (99%)	15 (99%)	35 (95%)	65 (93%)	495 (50%)	77%
70%	0 (100%)	35 (97%)	10 (99%)	20 (97%)	45 (95%)	340 (66%)	77%

Conclusions. For protecting large and small areas of land from wind erosion the shelterbelt design model Shamim type proved to be the best one. Next to the shelterbelt design model Shamim type, there were two models namely Khalid type and Usman type respectively which were good in minimizing the wind erosion. But the influence of the shelterbelt models Khalid type and Usman type were limited only to small areas.

For providing protection to larger areas from the erosion, the air drainage in the shelterbelt proved to be the best between 60% and 70%. If the protection from the wind erosion is needed for smaller areas, the air drainage through the shelterbelt proved to be optimum between 40% and 50%.

5 – FINAL CONCLUSIONS

The shelterbelt model Shamim type proved to be the best in providing protection to large areas against moderate or stormy winds, but under the hard wind treatment Ali type shelterbelt model provided better protection than Shamim type. For protecting small areas, the shelterbelt models Ali type and Usman type proved to be the best in providing protection from the wind. For unknown circumstances, especially with regard to wind velocity, Ali type can be recommended.

The optimum air drainage proved to be between 40% and 50% for the shelterbelts designed to protect small areas. The results of the experiments also indicated clearly that the air drainage should be between 60% and 70%, when the areas to be protected are large ones.

The author recommends the Ali type shelterbelt design on the basis of his experiments results for using it in practice. This could be accomplished easily in the Netherlands by using poplars *(Populus nigra,* var. *italica)* and an under-storey of bushes of alder *(Alnus glutinosa)*.

Fruit trees, especially in tropical countries, should be encouraged for using in the shelterbelts, as most of the fruit trees which could attain considerable height are slow in their growth. Consequently in the beginning, the fruit trees should be used as the inner row of the shelterbelt so that it could grow under wind protection. Once the fruit trees are established they could be used as the windbreak directly.

In the following chapter, the author will bring forward the various aspects for planning a shelterbelt project.

Chapter VIII

PLANNING A SHELTERBELT PROJECT

The farmers in the Netherlands are educated and practice scientific methods of cultivation. Therefore, when the agricultural extension service of the Netherlands explains the value of shelterbelts to the farmers, they will understand easily. Consequently, the Dutch farmers will establish and maintain the shelterbelts. Thus the Goverment of the Netherlands does not consider it necessary to maintain direct control over shelterbelt establishment or maintenance, believing it sufficient to provide technical assistance to farmers when needed. The conditions of the farmers in the countries of Western Europe and North America are similar to those of the Dutch farmers. However, the circumstances are different in most of the other countries of the world. Their farmers are neither educated nor prosperous. In addition, their lack of education makes them indifferent towards conservation generally, and in some cases might well lead them to strongly oppose a programme of shelterbelt establishment. Under these conditions, any shelterbelt undertaking should be handled directly or indirectly by the Government.

Certainly it is wise to start an experimental shelterbelt programme well before launching an extensive planting project. The research should be carried out on the various local problems which are faced during the establishment of shelterbelts. New designs may be developed which may suit the local conditions. Efficient methods of planting should be found. Problems arising from the maintenance of shelterbelts should be brought forward. The research should include the administrative difficulties which may arise due to lack of good transportation, equipment, or technicians.

Besides the research programme, there should also be carried out an educational programme among farmers at the same time. The farmers should be persuaded to understand the value of shelterbelts and the benefits which they would receive from them. General conservation education on a large scale should also be carried out. For this purpose, radio, television, movies, newspapers may be used. Volunteers from the universities and schools should be called upon to give help for carrying out educational programmes about the importance of shelterbelts among the villagers. Powerful slogans should be used for attracting the attention of the public. The major reason for carrying out the above educational programme is to secure the maximal cooperation from the public.

There are many ways to carry out a shelterbelt establishment programme. But the author brings forward three approaches: The first is the direct government approach in which the Government buys the land, later establishes and manages the shelterbelts itself. The second is the cooperative approach, which consists of establishing shelterbelts by the farmers with the cooperation of the Government. The third is the district approach. This approach leads to the establishment of shelterbelts by the district councils with the cooperation of the Government. These three approaches are discussed below.

1 – Direct Government approach

As the average farmer of most of the countries of the world is poor, the Governments of the respective countries should finance most of the project. Even in the U.S.A., most of the expenses in establishing shelterbelts in the Prairie Region were borne by the United States Government. At the outset of its programme, the United States Government actually purchased the strips of land on which shelterbelts were established. Although this procedure was abandoned after one year, it offers an opportunity for success to many countries.

The Government may buy the pieces of required land for the establishment of shelterbelts by paying to the farmers a reasonable compensation and also giving them the assurance of employment in the establishment and management of shelterbelts. This might make it easier for the Government to procure land for the establishment of shelterbelts. Later on the Government may establish shelterbelts at its own expense and hand over the management and utilization to its Forest Service or to a new independent organization such as 'Wind Protection Development Authority', for the administration of the shelterbelt programme. The shelterbelts should be managed as other Government owned property. The timber and other products of shelterbelts would be owned by the Government. For the complete success of the programme, it is necessary that the shelterbelts should be managed properly later on, so that the maximum benefits would be secured from the project.

The direct Government approach as outlined above has the possibility of the greatest success in the new developing countries of the world. The obvious reason for it is the poor and illiterate farmers of those countries, who cannot afford to establish a shelterbelt and are ignorant about the advantages of shelterbelts. Although the cost seems too high for completing the shelterbelt programme by means of direct Government control, in the long run the shelterbelts will repay the Government by preventing the silting of canals and later being the source of revenues by producing timber and fuelwood.

2 – Cooperative approach

In most of the countries in the world the farmers live in villages. The village is the social and economic unit of farmers. A cooperative undertaking would be more succesful, therefore, than if a project is undertaken individually. For example, shelterbelts established for the protection of a village from cold and hot winds is not the affair of an individual farmer. It can be successful only if all the villagers undertake to establish these shelterbelts cooperatively. The failure of their cooperation would also result in failure of their undertaking.

The farmer, who owns a small holding, cannot afford to build up a shelterbelt individually. Therefore, there is the necessity of a cooperative effort for creating shelterbelts by the villagers. Thus the formation of the cooperative societies is necessary for carrying out the shelterbelt establishment and maintenance successfully in villages. Some difficulties may arise, because it is not possible for the villagers to force everyone to join the cooperative society. As the cooperative society is formed on a voluntary basis, therefore, the indifferent attitude of a few villagers might make it impossible for the formation of a cooperative society. This difficulty might not come in every case. Cooperative societies may be formed in the villages that would contribute the land for the establishment of shelterbelts and the Government should subsidize the whole or most of the expenses for this. The Government should (1) furnish nursery stock; (2) examine and approve or reject proposed planting site; (3) give advice and guidance on cultivation and other subsequent care; (4) make available without cost special cultivation equipment in some areas; and (5) assist in rodent control by furnishing poison materials. The cooperative society on its part should (1) furnish land without cost to the Government; (2) prepare site for planting; (3) perform necessary subsequent cultivation and other care; (4) provide fencing material and construct a fence around the planting; and (5) protect the planting from fire, livestock and other injurious agents.

Later on maintenance of the shelterbelt will be the entire responsibility of the cooperative societies. The timber and other fuelwood removed from the shelterbelt will be owned by the cooperative society of the village. But the cooperative society should not be allowed to do any process of the cutting without getting permission from the District Forest Officer of the Forest Service.

The cooperative approach has good chances for success in establishing shelterbelts in many countries of the world, but it will face many difficulties. The formation of a cooperative society is not an easy task and to run it successfully will be another problem. Necessary regulations should be made, so that the cooperative society works smoothly. As a cooperative society is formed on a voluntary basis, many farmers might not take any interest. Then it will be almost impossible to form a cooperative society. Later, in some cases, a cooperative society might result in complete failure due to lack of cooperation among the members. The cooperative approach may prove a great success if it is applied a little later, when the shelterbelt establishment programme is well ahead and the farmers can realize the value of a shelterbelt. When the farmers start to take keen interest in the establishment of shelterbelts, the cooperative societies will emerge in great number and will run with a great success.

3 – District approach

The shelterbelt project may be carried out in each district (or county) by the District Councils with the cooperation of the Government. By the District Council the author means the local government of the district, whose members are the elected representatives of the district. District Councils may buy the lands and also contribute their own for the project. The Provincial and the Central Governments should pay at least half of the expenses which will result during the establishment of shelterbelts. The Provincial and the Central Governments should (1) furnish nursery stock; (2) examine and approve or reject proposed planting site; (3) furnish planting crew; and (4) give advice and guidance on cultivation and other subsequent care. The District Council for its part should (1) furnish land without cost to the Provincial and the Central Governments; (2) prepare site for planting; (3) perform all necessary subsequent cultivation and other care; (4) provide fencing material and construct a fence around planting; and (5) protect the planting from fire and livestock.

Later on maintenance of shelterbelts may be the entire responsibility of the District Councils. The timber and other fuelwood removed from the shelterbelt may be owned by the District Council. The District Council must have its own forester, well trained and qualified from an university in the profession of forestry. If the District Council do not have their own forester, then they should not be allowed to do any cutting without a permit from the District Forest Officer of the Forest Service.

The District approach could prove a great success in carrying out the shelterbelt programme in many countries of the world, if the District Councils cooperate sincerely with the Provincial and Central Governments and put the maximum efforts in carrying out the shelterbelt programme. This will require first to convince the members of the District Council about the importance of shelterbelts, and later to carry on an educational programme in the district for the purpose of gaining cooperation from farmers in carrying out the establishment of shelterbelts successfully.

4 – CONCLUSIONS

The experimental shelterbelt programme associated with intensive research on the various local aspects of the shelterbelt problems and a large scale educational programme to the farmers with a point of view to persuade them to understand the value and benefits of shelterbelts, are the strong foundations on which a large scale shelterbelt programme should be based.

In the Netherlands and similar countries, where the farmers are educated and practice scientific methods of cultivation, there is no need to maintain a direct control over the establishment and maintenance of shelterbelts by the Government and it is sufficient to provide technical assistance to farmers when needed. But in most of the other countries of the world where the farmers are illiterate and poor, the Government of these countries may have to finance most of the expenses involved in the establishment of shelterbelts. Along with it, the Government should start a large scale propaganda campaign. Only in this way, the Government might be able to encourage the farmers and the common people to come forward in this great project. Later on the Government may gradually reduce subsidies offered for the establishment of shelterbelts. Once farmers and the people at large understand the practical value of the project and see some of its effects, the project will be accepted more readily throughout the country. The Government should start the project first in a small region which is suffering the most and extend it to other parts.

In the next chapter the author will discuss the administration for a shelterbelt establishment and maintenance programme.

Chapter IX

ADMINISTRATION OF A SHELTERBELT PROGRAMME

1 – General history of shelterbelts [1])

The value of shelterbelts was recognized by different countries of the world quite early. In Russia, the first recorded planting of trees for shelterbelts was made in the early nineteenth century by German farmer immigrants who settled in the steppe region north of Crimea. The shelterbelt establishement started in the Crown States in 1872. After that time no large scale projects were developed until about 1880 when windbreaks were established on a 2700 acre land in Kherson district. In 1891, a severe drought occurred in Southern Russia. As a consequence, extensive research was inaugurated, in order to find its causes and to protect agricultural lands against future disaster. Shelterbelt planting was considered a major measure. The revolution somewhat retarted the development of shelterbelts. Many plantations were badly culled and some were completely destroyed.

In recent years, however, shelterbelt planting has been resumed on a large scale. The Council of Ministers of the U.S.S.R. and the Central Committee of the All-Union Communist Party on October 20, 1948, passed a resolution which raised the question of the creation of a system of large U.S.S.R. national protective shelterbelts (102). The resolution ran as follows:

'To overcome the destructive influence of dry winds upon the yield of agricultural products, to protect the fertile soils of the Volga area, the Northern Caucasus, and the Central Chennosem belt, from erosion by winds, and to improve the water regime and the climatic conditions of these regions – the creation of eight large national shelterbelts during the years 1950–1965 is recognized as necessary.'

Within this programme of eight shelterbelts, it was decided to create a national protective shelterbelt, stretching between Kamyshin and Stalingrad, along the watershed of the Volga and Horlya rivers, consisting of three zones, each 60 metres wide, spaced 300 metres from one another and 170 km long (102). In this fifteen year plan of water and soil conservation in the Volga basin, the U.S.S.R. Government intends to cover 775 sq km surface area under the forest barriers. In addition to this, field shelterbelts are to be planted over an area of 36,600 sq km and 2116 sq km of shifting sand have to be fixed by planting. The total area to be planted between 1950 and 1965 will amount to 39,491 sq km.

Few tree planters were among the earliest settlers of the United States of America. They came when westward migration started to the prairies of Illinois and the Great Plains. These pioneers realized that it was going to take more than a sod house to give them the protection to which they had been accustomed in the wooded east. It was not surprising, therefore, that a plantation of trees often shared with the garden the first patch of sod that was broken. There are records of some of these plantings having been established in Nebraska as early as 1854. Many are still alive, monuments to the courage of the pioneers and evidence of the desirability of using hardy, native planting stock (217).

[1]) For details of literature, please refer to Shah (196).

The passage of the Homestead Law in 1862 brought more settlers to the Great Plains which served to focus more attention on the need for tree planting. Kansas was the first state to encourage the establishment of forest plantings in the Plains region, enacting a treebounty law in 1865. This was followed in 1869 by Nebraska and the Dakota Territory which passed tax-exemption laws that favoured tree planting. The Dakota Territory Law of 1869 exempted from taxation 40 acres of land on any farm, and all improvements not exceeding U.S. 1,000 dollar in value on that acreage, provided trees were planted on five acres. Mr. J. Sterling Morton, Secretary of Agriculture, founded Arbor Day and saw its first official celebration in his home state of Nebraska in 1872. It was primarily through his encouragement that the Timber Culture Act was passed by Congress in 1873. Under the Timber Culture Act, title to 160 acres of land was granted to homesteaders who planted 40 acres of trees and protected them for ten years. Although it helped to stimulate tree planting, probably fewer than one-third of the trees established during the time the act was in force can be attributed directly to it. There was a period in the United States after the repeal of the Timber Culture Act in 1891 when little public encouragement was given to the planter. A renewal of interest was shown in 1904 with the passage of the Kincaid Act and later in 1916 by the inclusion of demonstrational tree planting in the programme of the Northern Great Plains Field Station situated at Mandan, North Dakota. The next major step was taken in June 1934, when the U.S. Government launched the 'Prairie States Forestry Project', a proposal to plant shelterbelts on about 1,282,000 acres of farmland lying within a zone of 100 miles in width extending from Canada southward through the central Plains to Texas.

In 1934, the U.S. National Resources Board estimated that the annual loss through wind erosion was U.S. $ 219,000,000 and they suggested an annual expenditure of U.S. $ 11,240,000 on control measures would be justified. A single storm in 1934 was estimated to have removed 300 million tons of fertile top soil off the wheat plains. The annual loss due to wind erosion showed by the National Resources Board emphasized the need for the development of the Shelterbelt Programme in the U.S.A.

In 1935, when shelterbelt planting in the Plain States began, approximately one million dollars were made available from an appropriation by Congress for the relief of the inhabitants of the drought-stricken plains. The project was not planned initially as a cooperative undertaking between the Federal Government as it is today. This was due largely to the fact that the money was appropriated for direct relief to farmers, and also because it was considered desirable to exercise complete control of the land in order to test the feasibility of the programme (62).

In May 1937, with the passage of the Norris-Doxey Act, Congress gave the project functional authorization and the official title of the 'Prairie States Forestry Project'. It was defined as a cooperative programme to be carried out by the Government and the individual farmer, and the scope of the programme was broadened somewhat. The Project was in operation from 1934 to 1943. During that time nearly 19,000 miles of shelterbelts were planted on approximately 33,000 farms.

In Canada the early settlers planted trees about their homesteads for a shelter against wind. But failures occurred due to use of unsuitable species and lack of tree culture. Experiment stations to study suitable tree species and techniques were started in the Canadian Prairie area. A nursery station to test the suitability of plants was established at India Head, Saskatchewan and later on at several other places. In 1901, a system of cooperative planting was begun by the Dominion Forestry Branch whereby the farmers were supplied with planting material free of charge on the condition that they would small central staff. Actual field work was directed and supervised by a 'Shelterbelt Assistant' who occupied a position which could be compared to a 'District Forest Ranger' in the national forests with respect to administrative and managerial duties. Generally, these men were recruited from the ranks of technically trained foresters. On some of the larger districts these local men had one or more assistants. Size and delineation of shelterbelt districts were normally determined by work load based on factors such as amount of plantable areas, interest of farmers, number of applications for shelterbelts. Some of the districts were composed of several counties (149).

During the time this project was administered by the Forest Service there was a considerable change in guiding policies. In the beginning (1934) there were two major objectives which were: (*a*) to provide employment during that period of severe economic depression; (*b*) to control wind erosion and its harmful effect upon agricultural land and cultivated crops. Other benefits of shelterbelt plantings, such as protection of farmsteads, control of snow drifting, providing shelter areas for livestock, improving wildlife habitat, providing farmers with a ready source of fence posts, fuelwood, poles, etc., were all given proper weight, but the control of wind erosion was paramount.

At first it was thought and planned that the Federal Government might either purchase or obtain long-term leases on the privately owned lands upon which shelterbelts were to be planted. Under such arrangements the Federal Government would be responsible for doing all of the work and for all costs. This position was soon changed, as it was found to be undesirable and too costly. Perhaps the most objectionable feature was that such an approach did not encourage the farmers themselves to become interested in the shelterbelts.

Beginning in 1936 the policy was materially changed and the initiative for requesting federal assistance for shelterbelt planting was placed upon the farmers themselves. The Federal Government dropped all leasing or land purchase plans. All subsequent plantings were made under a single cooperative agreement between individual farmers and the project. The aim was to let the landowner assume an increasing proportion of the responsibility and cost for the establishment of shelterbelts (62).

As economic conditions improved, more of the responsibility and work was shifted to the farmers. The result was that by 1942, when the project was transferred to the Soil Conservation Service, the work was accomplished about as follows. The Federal Government (1) furnished nursery stock; (2) examined and approved or rejected proposed planting site; (3) furnished planting crew if the work was to be done by hand; (4) furnished planting machine, foreman and planting machine operators; (5) gave advice and guidance on cultivation and other subsequent care; (6) made available without cost special cultivation equipment in some areas; and (7) assisted in rabbit control by furnishing poison material or transportation for voluntary hunting crews. The landowner on his part: (1) furnished land without cost to the Government; (2) prepared site for planting; (3) furnished tractor and driver when planting machine was used; (4) performed all necessary subsequent cultivation and other care; (5) provided fencing material and constructed fence around planting; and (6) protected the planting from fire.

As a general policy replanting by the Forest Service was limited to one year old shelterbelts and then only to those shelterbelts in which the losses were such as to justify the cost of replanting. For example, a twenty or thirty percent loss evenly distributed would not warrant replanting, whereas the same loss concentrated in a single species or area would justify replanting.

In addition to individual farmer cooperation, cooperation from county and municipal governments, civic bodies, and other interested organizations and individuals was increased every year. In 1939, for example, fifty-seven trucks were loaned to the project during the planting season by the counties. Some of the counties even furnished drivers and paid operating costs. Space for forty-two field offices, storage space in thirty-five warehouses, ground space and water for heel-in beds and numerous other services were donated, all of which if given a monetary value would amount to many thousands of dollars (62).

The simple cooperative agreements under which the work was done were not binding upon the farm owner. He was free to use the products of the planting, although the Forest Service endeavoured to guide these uses through advice and consultation from the local, technically trained shelterbelt assistants.

Much of the very early publicity about the project described it as a plan whereby a series of continuous shelterbelts would be planted from northern Texas to the Canadian border. Actually, the programme was never planned in that manner. Rather, the programme was one of planting on an individual farm basis so as to best provide wind protection for each specific farm. On some large areas of unfavourable soils, the so-called shelterbelt zone, no plantings were made.

In 1941, the Budget Bureau of the Government took the opinion that the shelterbelt programme should be under the Soil Conservation Service, and consequently it was transferred to that agency effective July 1, 1942. This transfer of administration of the shelterbelt project from the Forest Service to the Soil Conservation Service was made by the Secretary of Agriculture as a part of a reorganization of Departmental activities among the several bureaus of the Department. The principal reason given for this particular change was that transferring responsibility for the shelterbelt work to the Soil Conservation Service would enable the Department of Agriculture to carry out all of its programme of providing technical assistance for soil and water conservation work through a single bureau of the Department. The need for continuing the shelterbelt programme to provide employment had disappeared with the outbreak of World War II. It was also argued that the planting of field shelterbelts and farmstead windbreaks was essentially a part of farm planning and operation, rather than a forestry practice.

2.2 – The U.S. Shelterbelt Programme Administration as a Soil Conservation Project. Established pursuant to the Soil Conservation Act of April 27, 1935, the Soil Conservation Service functions as a direct-action agency of the Department of Agriculture with major responsibility for bringing about physical adjustments in land use such as will prevent floods and erosion and thereby conserve basic soil and water resources. To accomplish this task, the agency carries on a comprehensive and coordinated programme of soil conservation and land use, the principal operations of which are concerned with getting proper land-use changes and needed conservation practices applied on all farm and ranch land in the nation. The work centers chiefly around the preparation of complete farm conservation plans based on the needs and capabilities of each acre of land.

Technical personnel of the Service are specialists in determining land needs and methods of solving land and water problems. Staffs are composed of agronomists, agricultural, hydraulic and cartographic engineers, biologists, woodland specialists, soil scientists, range management specialists, and land-management and conservation planning technicians. Though specialists in one or more of the agricultural sciences, soil conservationists are trained to coordinate all knowledge pertaining to land and water for the special purpose of planning and applying land-use adjustments and conservation practices needed to repair erosion damage, increase yields, preserve and improve productivity of soils, and conserve water resources.

The Service's over-all programme is administered by the Administration and its staff from the Central Office in the United States Department of Agriculture in Washington, D.C. The Service maintains fifty-one State and Territorial Offices which perform technical and administrative functions to provide service to field personnel.

Each State or Territorial Office serves as headquarters for a State conservationist, a conservation engineer, a soil scientist, and a soil conservationist, who together serve the area offices and work units of the respective states. Each of the hundred area officers supervises several of the 3,083 work units. Each work unit is staffed by a professional conservationist and one or more aids, who work directly with farmers and ranchers.

Subject matter specialists (engineering and watershed planning specialists, plant technologists, and cartographic field units), each serving a group of states, are located strategically throughout the United States to provide scientific and technical guidance and training, and for production of soil maps, farm plans, and other essential working materials.

From the outset of its programme, the Soil Conservation Service has adhered to the fundamental assumption that (1) primary responsibility for achieving soil and water conservation and proper land use rests with the owners and operators of the land; (2) owners and operators will accept this responsibility voluntarily once they understand its importance to their own welfare and to that of the nation, provided the public assumes its share of the burden in proportion to the benefits it will receive through the realization of the objectives; (3) local problems of soil and water conservation require the development of local programme by land owners and operators if the programmes are to be carried out successfully; and (4) the Soil Conservation Service can best discharge its responsibilities by assisting organized bodies having authority established under state law in carrying out their local programmes pertaining to soil and water conservation and land use.

Shelterbelt plantings were included as a regular part of the soil and water conservation programmes as administered by the Soil Conservation Service, though Soil Conservation Districts' federal aid is limited to technical assistance and advice with respect to selection of planting sites, site preparation, selection and care of planting stock, size, composition and location of planting, techniques of planting and subsequent care and management.

Supervisors of Soil Conservation Districts have assumed several necessary functions, such as inclusion of shelterbelt planting in the District's conservation programme, encouraging local farmers to plant shelterbelts, pooling or purchase orders for planting stock.

Planting stock is purchased by the individual farmers from commercial and State-owned nurseries, but part of these costs may often recovered by the farmer through incentive payments made by the Agricultural Conservation Programme. Similar financial assistance is also sometimes available for other related costs, such as those incurred in fencing and cultivating.

Perhaps the most important change in administrative policy is that the shelterbelt planting programme is no longer conducted as a single-purpose, seperate project, but is carried out as merely one aspect of soil and water conservation. Under such an arrangement very few technically trained foresters are employed, and the technicians who guide the programme and work with individual farmers have been trained mostly in agronomy, soils, or crops production.

3 – Conclusion: A proposed administration for a shelterbelt project

Although some farmers used trees for the protection of their homes and fields from wind as early as the eighteenth century, they were not in a position to assess the real value and the importance of protection provided by the trees, due to lack of education and information. Gradually the damage caused by the wind became more obvious and its adverse effects on the agricultural economies of the nations also were evident. Consequently many countries carried out shelterbelt establishment programmes for the protection of their agricultural resources.

To fight the destructive influences of the wind, the U.S.A. and the U.S.S.R. carried out large scale programmes. The study of the development of the U.S. Prairie States Forestry Project indicates that the establishment of the shelterbelt was a slow process. The U.S. Shelterbelt Project which covered the region from the Canadian border to the northern region of Texas was not carried out simultaneously, but the shelterbelts were established from farm to farm according to its requirements. Hence the success of the shelterbelt establishment programme in a country largely depends on the interest of its farmers. The farmers should be supplied with appropriate information regarding the shelterbelts so that the proper interest can be created among them before the shelterbelt establishment project can be carried out.

In a direct-action programme for fighting against the adverse effects of wind successfully on a large scale, there is a need of an independent organization for carrying out the shelterbelt project which should be responsible directly for carrying out the project. In this organization which could be named as 'Wind Protection Development Authority', technically well qualified hands should be recruited. The head of the organization should be a Director with various sections directly under him, for example, Silvicultural Section, Soils, Fiscal Control, Operation, Personnel Management, Public Relations, etc. The shelterbelt establishment project area could be divided into a number of divisions. The head of each division should be known as Assistant Director and also should be provided with a small central staff. Each division should be further divided into districts. The head of each district should be a Shelterbelt Assistant, who will be responsible for the supervision of field work. One or two assistants should be provided to the Shelterbelt Assistant according to the work load. The policy for conducting the shelterbelt establishment project should be based on cooperation basis. In the beginning the Government should provide some kind of subsidy for attracting the farmers for the establishment of shelterbelts. Gradually the maximum responsibility and the costs for establishing the shelterbelts should be shifted towards the farmers.

In the following chapter the author will bring forward various aspects and tools for the maintenance of shelterbelts.

Chapter X

MAINTENANCE OF SHELTERBELTS

The successful establishment of shelterbelts requires patience and continual interest on the part of the owner. Short-cuts usually end in failure. If the desired benefits from shelterbelts are to be fully realized, it is very important that they must be given proper care. In other words, the successful establishment of shelterbelts lies in their later management and maintenance. Protection, cultivation, thinning and utilization of trees comprise the most important phases of shelterbelt management.

1 – Protection

Read (178) and Edmondson (77) have emphasized the importance of protecting shelterbelts from fire, livestock, rabbits, and plant diseases. The two major enemies of trees are fire and livestock. When fire occurs, it is usually sudden and its destruction is complete; it brings to naught the years of care. It is essential that fire protection measures should be undertaken, and that firebreaks should be made: strips of plowed or cleared land made to check the spread of a forest fire.

The damage caused by livestock is as sure as fire in destroying eventually the shelterbelt. Browsing of shrubs and the lower branches of trees and young production opens up the stand to the drying effects of winds, allows the snow to blow through, and generally reduces the effectiveness of the planting (217). Constant trampling by stock compacts the soil and seals the surface, thus allowing a smaller amount of the precipitation to reach the tree roots (178). The trampling may injure the roots or result in breakage or other damage to the stem of the tree. The damage from livestock can be prevented by keeping the livestock away from shelterbelts. This may be accomplished by building a fence around the shelterbelt. Den Uyl (68) points out that the fences should be placed at least ten feet from the outside rows of trees in order to avoid the damage from livestock that reach over the fence.

Poultry, rabbits and rodents are also often a major source of damage to shelterbelt plantings. Chickens will pick off the tender buds of evergreens in the early spring. They also will scratch in the soil under trees and often expose and kill many of the surface roots. Geese will completely defoliate small evergreen trees. When poultry is allowed to roost in evergreens, the accumulation of manure will sometimes kill the trees. Therefore it is necessary to keep poultry away from the shelterbelts. A fence may be built around the shelterbelt for the protection from poultry. Rabbits can injure or kill young trees during the winter months. They eat the needles, young shoots, and strip the bark. The shelterbelt can be protected against rabbits while the trees are small by placing closely woven wire around each tree. When the shelterbelt is grown up, the rabbits are controlled either by poisoning or by hunting. Rodents are also a serious pest. Mice can girdle trees up to four inches in diameter. Pocket gopher can completely sever roots three to four inches in diameter and frequently cause the death of trees up to twelve feet in height (245). Different poisons may be used to control rodents.

Various insect pests attack young trees. Insects may feed on the foliage, on the stem, and on the roots. Defoliation of a tree may not kill it, provided it is growing vigorously and the injury is not repeated, but loss of leaves does weaken the trees (208). Clean cultivation and other good cultural practices are beneficial in reducing insect damage. It is necessary to keep a good check on the control of insects and plant diseases.

2 – Cultivation

Studies (96, 118) have shown that thorough cultivation is necessary during the first three to five years of the life of a shelterbelt plantation. No amount of careful site preparation and good planting will compensate for neglect in cultivation. Frequent cultivation at proper intervals conserves moisture in the soil. This helps to carry trees over dry periods that are sure to come in the summer. Cultivation should be shallow and not close to the trees, or the roots immediately below the surface will be cut off or pulled out (13). Cultivation should start as soon as weed growth appears and should continue throughout the growing season. Experiments have shown that cultivation is stimulating to tree growth, only few trees die, and it is one of the most effective means that can be used in the growing of tree windbreaks (68). Cultivation must be kept up each year, particularly under dry land conditions until the trees have reached a size when it will not be possible to use a team and cultivator between the rows. The life of the tree will depend upon the thoroughness of cultivation.

Soil should not be hilled up around the trees, especially around evergreens (13). Roots of the trees as well as the leaves need air. Piling soil high will encourage the growth of an extra set of surface roots, causing the lower and more important roots to cease functioning. During the first few years when the trees are small, corn or some other cultivated crop may be drilled in between the rows. It is important that care should be taken to keep the crop from direct competition with the trees for moisture and light. When such crops are grown between the tree rows, ample space should be made for the use of cultivating implements, so that in cultivating the agricultural crop the trees will also be cultivated.

After the corn is picked, the standing cornstalks may be left over winter. This helps to catch and to hold snow around the trees preventing or reducing danger of winter-killing. If cultivation is neglected and weeds and grass are allowed to spring up, then it is not advisable to resume cultivation during periods of hot and dry weather. Sudden exposures may be more injurious to trees during such periods than weed growth. Weeds and grass should not be allowed to continue to grow in the planting following periods of dry weather, but should be taken out as soon as it is possible to cultivate. Cultivation should be continued each year as long as possible physically or at least until the trees are high enough to shade and to protect all of the ground. Otherwise grass and weeds will come in to crowd, retard or kill tree growth (49).

Mulching may often be used to advantage as a supplement to or substitute for cultivation. This consists of placing some material such as straw about the base of the plant. Heavy straw such as that of flax, wheat or soybeans is most suitable since it will not blow so badly. Coarsely ground corncobs or sawdust also make an excellent mulch. The mulch should be as clean as possible. Any weed seeds of grain in the mulch will often attract poultry which can seriously harm the trees (177).

There are four good reasons for mulching. (*a*) Mulching prevents weed growth about the trees and reduces the amount of cultivation necessary. If sufficient mulch is available to cover a strip five to six feet in width along the entire row of trees, the problem of cultivating the area between the trees in the row is solved (70). (*b*) Mulching helps to hold moisture. During dry periods, in winter or summer, a good mulch will often save a tree from damage or death. (*c*) Mulching protects newly planted trees against frost heaving, since it helps to maintain an even surface soil temperature throughout the winter. (*d*) Mulching increases the early growth rate of the trees. The effect is especially noticeable during dry seasons (68).

There are also a few disadvantages of mulching which should not be overlooked before applying it. Mulch sometimes attracts rodents, especially mice, which may girdle small trees. The other disadvantage of mulching is that it tends to encourage surface roots because moisture is held close to the surface (77). As a result, roots are not forced to go down into the ground for needed moisture and food. Surface roots thus developed are more susceptible to drought and winter-killing (12).

It is important that manure or manured straw should never be used, as it will harm the trees. It is advisable to place the mulch for a radius of about two or three feet around the tree and up to within a few inches of the stem. There is a greater possibility of mice damage if the mulch is placed in contact with the stem of the tree. Enough mulch should be placed around the tree so that weeds and grass will not grow through it. More mulch should be added when it has settled or decayed. It is advisable to examine the mulch frequently for the presence of rodents, especially field mice, and place poison bait if rodents are present.

3 – Thinning

Smith (208) and Westveld (244) have stressed the importance of thinnings in shelterbelts and recommend their use. Just as soon as the lower branches of the trees begin to interlace, they recommend the removal of every other tree from the belt. If this is not done, the competition for light will kill the lower branches and the lower portion of the shelterbelt will be open and less effective as a windbreak (49). Shelterbelts require thinning during their period of growth and development because all trees do not grow at a uniform rate. Thus, it is necessary to take out some of the less desirable trees to provide growing space for the best trees.

Experience has shown that thinnings should be so planned that the final spacing of trees will be 16 by 16 feet or 24 by 24 feet (68). This spacing can best be attained by a series of light thinnings which will gradually provide space for the best trees to develop. Trees that have been spaced 5 or 6 feet apart in rows usually will require thinning in 5 to 8 years. Trees spaced 12 feet apart when planted can grow for 10 years or more before the side branches grow out and occupy the space between the trees. The removal at this time of alternate trees and rows should be done over a period of two or three years so that the trees that are left will gradually adapt themselves to the changed conditions. Heavy cutting that causes sudden opening of the stand will in most cases result in the death of some trees and poor development of others. Walker (235) pointed out that in closely planted shelterbelts, a good deal of thinning takes place naturally. This natural thinning may take place in the form of branches broken or damaged by wind, hail, snow, cold or general weakness, failure of a particular kind of tree to hold its own against its neighbours.

The first type of natural thinning is more or less beyond the control of the tree planter and under certain conditions must be expected occasionally from one cause or another. The chief concern of the tree planter is to repair such damage as best as he can without undue delay, for the future welfare of his trees. The second type of natural thinning, namely the suppression of naturally weak trees, which may appear in any population, operates throughout each season. As time passes, the difference between vigorous and weak trees becomes more pronounced, the latter finally reaching the stage where they make little growth or in many cases die. Chiefly because of this latter condition and because it is not possible to pick out those young trees which are likely to do best, thinning of closely planted shelterbelts should not be practiced too soon.

It is a folly, nevertheless, to allow trees to die in a shelterbelt because of overcrowding. The better plan is to cut out a sufficient number of short lived trees as soon as the wood obtained from them will make as significant contribution towards fuel, fence posts or other timber needs. When thinning is done, there should be no question about the remaining trees continuing to make vigorous growth. Certainly little thinning will be needed during the first five years after planting a shelterbelt. Thinnings should be done cautiously for two other main reasons – to avoid exposure and drying out of the forest floor, and to prevent rapid development of competitive weed growth.

4 – Pruning

According to Stoeckler and Williams (217), pruning of shelterbelts should ordinarily be confided to the removal of dead or diseased branches, broken limbs, or double leaders. The reason for light pruning is that maximum foliage and branching from top to bottom are essential to give the best possible wind-breaking qualities and to provide maximum ground cover (235). However, pruning a few of the lower limbs of trees that are to be removed later in thinning operations may be desirable. Trees so pruned can be left until their removal becomes necessary to provide space for the development of other trees. When there is crowding and lack of light within a well established shelterbelt, the lower branches seldom become strong; in other words, the lack of light and other conditions unfavorable for growth cause what might be called 'self pruning'. This phenomenon is more noticeable in some trees than in others. In mixed shelterbelts containing both evergreen and deciduous trees, the latter should be cut back when necessary. Damage to evergreen trees, on the other hand, is almost wholly irreparable and should be prevented as far as possible.

5 – Utilizing trees in shelterbelts

There are two main reasons why certain trees in established shelterbelts should be cut and utilized before they die. First, the wood of trees that have died has less value as fuel than wood of trees cut green and properly seasoned. Secondly, nothing is to be gained by leaving trees which are at a standstill so far as further development is concerned. In the case of shelterbelts, if the efficiency of trees in providing adequate shelter is impaired, it is sound economy to arrange to set out a new shelterbelt prior to removing the old trees. In other words, farmers should be urged to think of their shelterbelts as farm crops which should yield a harvest within more or less definite periods and, as such, new crops must be started occasionally. It should be noted, however, that the management of any shelterbelt does not call for the cutting of the whole planting at one time. The recommended plan (49) is that only those trees in a shelterbelt which are definitely weakest or whose reduced rate of growth renders them easy victims of attack by insects or diseases should be cut out at intervals of about five years. The expected result of this step is a stimulation of growth by the remaining trees. Instead of farmers thinking of their shelterbelt trees as fixed or permanent farm equipment, it is sounder economy to adopt an attitude towards them of greatest utility and service.

6 – Conclusions

Protection, cultivation, thinning and utilization of trees comprise the most important phases of shelterbelt management. The author emphasizes the importance of protecting shelterbelts from fire, livestock, rabbits, insect pests and plant diseases. The neglect in proper protection may destroy the beneficial effect of the shelterbelt completely. Cultivation is essential for the healthy development of the shelterbelt. Proper thinning and pruning increase the protective efficiency of the shelterbelt. Utilization of the shelterbelt trees as timber or fuelwood makes the shelterbelts a farm crop which should yield a harvest within certain periods and as such should be replaced periodically.

CHAPTER XI

SUMMARY

This study was carried out as an analysis which should yield a guide for a comprehensive understanding regarding the wind protection and the shelterbelts. The study was divided into two parts, dealing with the basic facts of wind protection and with the various aspects of shelterbelts. The research comprised the influence of the artificial windbreak on the development and yield of bean and maize crops in the field as well as in the wind tunnel in the laboratory, and the determination of the optimum shelterbelt design by means of models in the wind tunnel. The study included the planning, administration, history, establishment and management of the shelterbelts. The results are summarized as follows.

1. The primary effect of a shelterbelt is the retardation of the wind velocity which produces changes in the other ecoclimatic factors.

2. The growth and yield of bean and maize crops were better in the protected zone of the windbreak than in the non-protected zone of the experimental fields. The increase in the yield of bean and maize crops in the protected zone of the windbreak was 12% and 17% respectively. These values were lower than anticipated. In 1960 excessive rainfall induced accumulation of moisture in the protected zone of the windbreak, resulting in partial rotting of the bean plants. For maize the height and width of the windbreak of 2 m and 6 m respectively appeared to be too small.

3. In the experiment near to field conditions in the wind tunnel in a glasshouse at Wageningen the growth of bean and maize plants was much better in the protected zone of the windbreak than in the non-protected zone. The yield of bean seeds was no less than 67% higher in the protected zone as compared to the yield in the non-protected zone. The yield of bean seeds and dry weight of maize plants in the pot experiments resulted in higher yields of 28% and 11% respectively.

4. The major factors which are favourably influenced by the retardation of wind velocity by the shelterbelt are temperature, rate of transpiration, conservation of soil moisture and direct mechanical injury to plants. These result in an increased photosynthetic surface and a better shoot/root ratio. As a consequence, better growth and yield in the shelterbelt protected zone occur.

5. The selection of site, proper shelterbelt design and species are the foundations on which the establishment and the efficiency of the shelterbelt and its operation depend in future.

6. The author designed various types of shelterbelt design models for testing them in the wind tunnel at Groningen for determining the optimal design of shelterbelt. See figures 67–72 and tables 16–24. The shelterbelt design model Shamim type proved to be the best in providing protection to large areas, during moderate and stormy winds. The shelterbelt design models Ali type and Usman type proved to be the best in providing protection from the wind in smaller areas. The optimal air drainage for the shelterbelt designed to protect large areas was found to be between 60% and 70%, whereas it was between 40% and 50% for protecting small areas. The artificial windbreaks used in the field and the wind tunnel experiments corresponded with the Usman type shelterbelt design model.

7. For planning a shelterbelt project, it is necessary to modify the programme according to the local circumstances. The author has described three approaches: the direct government approach, the cooperative approach and the district approach. The direct government approach has greater chances of success than the other two approaches, especially in the newly developing countries.

8. An efficient administration is a necessity for implementing the plan of establishing the shelterbelts. In a direct-action programme for fighting against the adverse effects of wind successfully on a large scale the author recommends the establishment of an independent organization such as 'WIND PROTECTION DEVELOPMENT AUTHORITY', which should be responsible for carrying out the shelterbelt project.

9. The successful establishment of the windbreaks and the shelterbelts lies in its later maintenance. The most important stages in the successful management of the shelterbelts are protection, cultivation, thinning, pruning and the utilization of the shelterbelt trees.

RÉSUMÉ

Cette étude a été exécutée comme étant une analyse, dont le résultat pourrait être considéré comme un guide concernant les différents aspects de la protection contre le vent, et les rideaux-abris. On la divise en deux parties, dont l'une traite la base de la protection contre le vent, et la deuxième son application. Les recherches comprirent l'influence qu'ont les brise-vents artificiels sur le développement et la récolte des haricots bruns et du maïs, ceci soit à la compagne, soit dans un tunnel à vent à Wageningen, ainsi que de déterminer quelles sont les formes les plus favorables des rideaux-abris. A cet égard nous avons utilisé également un tunnel à vent à Groningen. En outre, cette étude donne des aperçus pour de grands projets sur le plan, l'organisation, l'histoire, le placement et la gestion. Les résultats se résument ainsi:

1. L'action directe d'un rideau-abri est de diminuer la vitesse du vent, ce qui amène des modifications indirectes de l'oecoclimat.

2. Les expériences faites sur les cultures des haricots et le maïs démontrèrent de meilleures croissances et récolte dans la zone abritée qu'en dehors. Cette augmentation atteignit respectivement 12 et 17%. Ces chiffres restèrent au dessous de ce que l'on attendait. Ceci fut causé d'une part par les précipitations démesurées de l'année 1960, ce qui amena un surcroît d'eau dans la régime protégée, et eut pour conséquence que beaucoup de haricots pourrirent. Pour le maïs, on constate d'autre part que l'étendue en zone abritée était trop petite, ceci de raison des dimensions trop exigues des rideaux artificiels (hauteur 2 mètres, largeur 6 mètres).

3. L'expérience faite dans le tunnel à vent dans une serre à Wageningen, soumise approximativement aux mêmes conditons qu'une culture à la campagne, donna pour ces deux céréales une croissance bien meilleure dans la zone abritée. La récolte eut une hausse de 67%. Les épreuves faites avec des pots rapportèrent davantage de haricots, ainsi qu'un plus grand poids des plantes sèches de maïs, respectivement de 28 et 11%.

4. Les principaux facteurs favorisés par la réduction de la vélocité du vent sont les suivants: la température, une évaporation lente, la rétention de l'humidité dans le terrain et le degré de l'endommagement mécanique et direct des plantes. De ces facteurs il en résulte une augmentation de la superficie photosyntétique et une relation plus favorable entre les parties de la plante qui sont sous terre et celles au dessus de sol. Les conséquences sont une croissance meilleure et une récolte plus abondante.

5. L'efficacité et l'effet des rideaux-abris sont déterminés par l'emplacement, la forme et les sortes d'arbres.

6. L'auteur projeta différents modèles de rideaux-abris, qu'il mit à l'essai dans le tunnel à vent de Groningen pour éprouver leurs qualités. Voir figures 67–72 et tableaux 16–24. Pour abriter de grandes superficies de terrain, en cas de vent modéré ou violent, le modèle du type Shamim donna les meilleurs résultats de protection, tandis que ceux des types Ali et Usman répondirent mieux

aux besoins pour de petits terrains. La perméabilité optimale du type premier fut évaluée à 60–70% et celles des deux autres de 40–50%. Pour les observations à la campagne et celles à Wageningen les rideaux du type Usman ont été utilisés.

7. Pour l'ébouche d'un plan de protection il est nécessaire de tenir compte de la situation locale. L'auteur considère trois manières respectives de mettre en pratique un tel projet: par le gouvernement, par la cooperative et par le district. La première méthode de travail est celle qui a le plus de chance de réussite dans de nouveaux pays.

8. Pour l'exécution de ce plan, il est indispensable d'avoir une bonne organisation. Pour combattre efficacement et sur une grande échelle les dégâts causés par le vent, l'auteur conseille d'établir une organisation autonome, par exemple 'WIND PROTECTION DEVELOPMENT AUTHORITY', ayant la responsibilité que le plan soit executé.

9. L'entretien des rideaux-abris est un point très important pour la réussite. Les principales parties d'une bonne gestion sont la protection, le travail de la terre, l'éclairissement, l'élagage et l'exploitation dus bois.

SAMENVATTING

Deze studie is uitgevoerd als een analyse, die zou kunnen resulteren in een leidraad ten aanzien van de verschillende aspecten van windbeschutting en windschermen. Zij bestaat uit twee delen, waarvan het ene de grondslagen van de beschutting behandelt en het andere de toepassing. Het onderzoek omvatte de invloed van kunstmatige schermen op de ontwikkeling en opbrengst van bruine bonen en mais, zowel te velde als in de windtunnel van het Laboratorium voor Tuinbouwplantenteelt van de Landbouwhogeschool, alsmede het bepalen van de gunstigste vormen voor de windschermen. Hiertoe werd eveneens een windtunnel gebruikt, en wel die van het Instituut voor Bodemvruchtbaarheid te Groningen. Bovendien bevat de studie beschouwingen over opzet, organisatie, geschiedenis, aanleg en beheer van windschermen voor grote projecten. De resultaten zijn als volgt samen te vatten:

1. De directe werking van een windscherm is windremming, die indirecte wijzigingen in het oecoklimaat bewerkstelligt.

2. De veldproeven toonden voor bonen en mais een betere groei en opbrengst in de tegen wind beschermde zone dan erbuiten; de vermeerdering van de opbrengst bedroeg resp. 12 en 17%. Deze waarden bleven beneden de verwachting. Enerzijds veroorzaakte namelijk de overmatige regenval van 1960 wateroverlast in de beschutte zone, met voor de bonen veel rotting tot gevolg. Anderzijds bleek voor mais de beschuttingszone te klein door te geringe afmetingen van het windscherm (hoogte 2 meter, breedte 6 meter).

3. De proef in de windtunnel in een kas te Wageningen, waarbij de omstandigheden te velde werden benaderd, gaf voor beide gewassen eveneens een veel betere groei te zien in de beschutte zone. De opbrengst was er niet minder dan 67% hoger. Bij potproeven bedroegen de meeropbrengst van bonen en het grotere drooggewicht van maisplanten resp. 28 en 11%.

4. De belangrijkste factoren die gunstige invloed van windremming ondervinden, zijn temperatuur, mate van verdamping, behoud van vocht in de grond en omvang van de directe mechanische beschadiging van de planten. Een en ander leidt tot vergroting van het fotosynthetisch oppervlak en tot een gunstiger verhouding tussen boven- en ondergrondse plantdelen. Bijgevolg zijn de groei en de opbrengst in de beschutting beter.

5. Doelmatigheid en werking van een windscherm worden bepaald door de keuze van plaats, vorm en houtsoorten.

6. De auteur ontwierp verscheiden modellen voor windschermtypen en beproefde ze in de windtunnel te Groningen. Zie de figuren 67–72 en de tabellen 16–24. Het model van het Shamim-type bleek het beste als bescherming van grote oppervlakten bij matige en harde winden, dat van het Ali-type en van het Usman-type het beste voor kleinere terreinen. De optimale winddoorlatendheid van het eerste type kon worden vastgesteld op 60–70% en die van de twee andere op 40–50%. In de veldwaarnemingen en die te Wageningen is gebruik gemaakt van windschermen van een Usman-type.

7. Voor het opstellen van een beschuttingsplan dient rekening te worden gehouden met de plaatselijke omstandigheden. De auteur onderscheidt hierbij drieërlei aanpak: die van regeringswege, de coöperatieve en de districtsgewijze. Vooral in de jonge landen heeft de eerste werkwijze de meeste kans van slagen.

8. Een doelmatige organisatie is onmisbaar voor de uitvoering. Voor een urgentieplan tot het met succes en op grote schaal bestrijden van windschade beveelt de schrijver het instellen aan van een zelfstandige organisatie, bijv. te noemen: 'WIND PROTECTION DEVELOPMENT AUTHORITY', belast met de verantwoordelijkheid voor de uitvoering van het plan.

9. Het welslagen van windschermen ligt besloten in het onderhoud. De belangrijkste onderdelen van een goed beheer zijn bescherming, grondbewerking, dunning, snoei en houtexploitatie.

SELECTED BIBLIOGRAPHY

1. ANONYMOUS, 1934: *Tree belt 100 miles wide*. Can. Forest and Outdoors *30*, 9, pp. 648–649
2. — , 1948: *How shelterbelts benefit crops*. Am. Nurseryman *88*, 11, p. 56
3. — , 1960: *The efficiency of coastal shelterbelts in the N. part of Kiangsu province (1958–1959)*. Forest Sci. (Peking) *2*, pp. 77–93
4. — , 1960: *Soil erosion by wind and its measures for its control on agricultural lands*. FAO Agric. Developm. Pap. no. 71, pp. 1–88
5. — , 1961: *Shelterbelts for farmlands*. Min. Agric., Fish. and Food (G.B.), Fixed Equipm. Farm, Leaflet no. 15, pp. 1–19
6. ABD EL RAHMAN, A. A. & J. F. BIERHUIZEN, 1959: *The effect of temperature and water supply on growth, transpiration and water requirement of tomato under controlled conditions*. Meded. Landbouwhogeschool Wageningen (Netherlands) 59(3), pp. 1–13
7. ABD EL RAHMAN, A. A., P. J. C. KUIPER & J. F. BIERHUIZEN, 1959: *Preliminary observations on the effect of soil temperature on transpiration and growth of young tomato plants under controlled conditions*. Meded. Landbouwhogeschool Wageningen (Netherlands) 59(15), pp. 1–12
8. ANDERSON, EDGAR, 1950: *The corn plant of today*. Pioneer Hi-Bred Corn Comp., Des Moines (U.S.A.), pp. 1–20
9. ANDERSEN, K. F., 1954: *Gales and gale damage to forests with special reference to the effects of the storm; 31st January 1953, in the North-East of Scotland*. Forestry, J. of Soc. of For. of G.B., pp. 97–121
10. AFANASIEV, M., 1947: *Trees and tree planting for post, windbreaks and erosion control*. Oklahoma Agric. Exp. Stat., Bull. no. B-314, pp. 3–23
11. ALLEN, R. W., 1915: *Windbreaks, hedges and ornamentals for irrigated sandy soils of eastern Oregon*. Oregon Agric. Coll., Exp. Stat. Corrallis, Stat. Bull. no. 125, pp. 3–24
12. ANDERSON, PARKER O., 1935: *Planting the standard windbreak*. Univ. Minnesota, Agric. Ext. Div., Spec. Bull. no. 168, pp. 2–8
13. — , 1949: *Planting the farmstead shelterbelt*. Univ. Minnesota, Agric. Ext. Serv., Ext. Bull. no. 196, pp. 1–16
14. ADRIANOV, S. N., 1958: *Est' li lesnog mikrklimat v polezascitnyh lesnyh polosah? (Do shelterbelts have a forest microclimate?)* Lesn. Hoz. *(*U.S.S.R.*) 11*, pp. 77–78
15. ARMOND, D. C., 1958: *Preventing erosion from hollows and gullies by tree belts along their brows*. Translat. Soviet Soil Sci. *2*, p. 147
16. ARNOLD-FORSTER, W., 1951: *Wind-shelter and wind-tolerance*. J. of Royal Horticult. Soc. (London) *76*, 10, pp. 341–347
17. ASLYNG, H. C., 1958: *Shelter and its effect on climate and water balance*. Oikos (Acta Oecol. Scand., Copenhagen) *9*, pp. 282–310
18. BATES, CARLOS G., 1911: *Windbreaks: their influence and value*. U.S. Dep. Agric., For. Serv. Bull. no. 86, pp. 1–100
19. — , 1917: *The windbreaks as an asset*. U.S. Dep. Agric., Farmers' Bull. no. 788, pp. 1–22
20. — , 1921: *Breaking the power of prairie winds*. Can. Forestry Mag. *17*, p. 336
21. — , 1934: *The plains shelterbelt*. J. of Forestry *32*, pp. 978–991
22. — , 1944: *The windbreaks as a farm asset*. U.S. Dep. Agric., Farmers' Bull. no. 1405, pp. 1–19
23. — , 1945: *Shelterbelt influences*. J. of Forestry *43*, 2, pp. 88–92, continued *43*, 3, pp. 176–196
24. — , 1948: *How shelterbelts benefit crops*. J. of Forestry *46*, 10, pp. 767–768
25. — , 1948: *Farm crops benefit from field shelterbelts*. Univ. Minnesota, Agric. Exp. Stat., Minnes. Farm and Home Sci. *5*, 3, pp. 6–7

26. BAIRD, W. P., 1957: *Ornamental hedges for the northern great plains.* U.S. Dep. Agric., Farmers' Bull. no. 2105, pp. 1–34
27 BEAN, LOUIS H., 1942: *Crop yields and weather.* U.S. Dep. Agric. and U.S. Dep. Commerce, Misc. Publ. no. 471, pp. 1–131
28. BEAVAN, ALAN, 1934: *Shelterbelts and groves.* Can. Forest and Outdoors *30*, 8, p. 595
29. — , 1947: *Ramparts of trees for every farm of the prairie west.* Can. Forest and Outdoors *43*, 2, pp. 39, 41, 55
30. BEK, L. O., 1957: *Plezazcitnoe lesorazredemie v S.S.S.R. (Shelterbelt planting in the U.S.S.R.)* Issledovanija i materialy Inst. po Izueenju, München (ser. 2), no. 56, p. 177
31. BENKOVITS, K., 1958: *Legelovedo fasitas. (Planting of shelterbelts on pastures.)* Hung. Agric. Rev. *7*, 2, p. 150
32. BESKÖK, E., 1957: *Koruyuw orman seritleri ve balâde, Koruyuw orman seritleni tesisi denemeleri. (Shelterbelts and establishment trials in Balâ).* Orm. Arast. Enst. tek. (Turkey), Bült. no. 7, pp. 1–138
33. BIERHUIZEN, J. F., 1958: *Some observations on the relation between transpiration and soil moisture.* Netherl. J. of Agric. Sci. *6*, 2, pp. 94–98
34. BLACKMAN, G. E. & G. L. WILSON, 1951: *Physiological and ecological studies in the analysis of plant environment; VI. The constancy for different species of a logarithmic relationship between net assimilation rate and light intensity and its ecological significance.* Ann. of Bot., new ser. *15*, pp. 63–94
35. BLACKMAN, G. E. & J. N. BLACK, 1959: *Physiological and ecological studies in the analysis of plant environment; XII. The role of the light factor in limiting growth.* Ann. of Bot., new ser. *23*, pp. 131–145
36. BODROFF, V., 1936: *The influence of shelterbelts over the microclimate of adjacent territories.* J. of Forestry *34*, pp. 696–697
37. BOIXO, P. DE, 1960: *De la protection des cultures contre les dégâts des vents à Cuxons (Pyr.-Ov.), Hénon (C.d.N.), Chevaia (Maroc.). (The protection of crops against wind damage at Cuxons (E. Pyreneas) Hénon (Côte du Nord) and Chavaia (Morocco).)* C. R. Acad. Agri. France *46*, 10, pp. 588–595
38. BONNER, DAVID M. & JAMES BONNER, 1948: *On the influence of various growth factors on the growth of green plants.* Am. J. of Bot. *27*, 1, pp. 38–42
39. BOOTH, G. W., 1934: *Prairie-farms or deserts of dust.* Can. Forest and Outdoors *30*, pp. 400–402
40. BRYANT, J. F., 1927: *Shelterbelts and prairie orchards.* Can. Forest and Outdoors *23*, 4, pp. 195–197, cont. *23*, 5, pp. 277–278, 289
41. BUDYKO, M. I. & H. P. POGOSJAN, 1954: *Change in climate of the air near the ground, caused by the improvement of drought regions.* Pririoda (Moskva) *43* (5), pp. 45–51
42. BURMISTROVS, A., 1958: *Därzu aizsargastädijumi latrigas P.S.R. (Shelterbelts for orchards and market gardens in Latvia.)* Trud. Inst. Les (U.S.S.R.), Probl. Riga, no. 14, pp. 237–250
43. CABORN, J. M., 1955: *The influence of shelterbelts on microclimate.* Quart. J. of Roy. Meteorol. Soc. (U.K.) *81*, pp. 112–115
44. — , 1957: *Shelterbelts and microclimate.* Forestry Comm. (U.K.) Bull. no. 29, pp. 1–135
45. — , 1959: *Shelterbelts.* Scott. Agric. *38*, pp. 199–202
46. — , 1960: *The planning of shelterbelts.* Scott. Forestry *14*, 3, pp. 123–129
47. CADMAN, W. A., 1953: *Shelterbelts for Welsh hill farms.* Forestry Comm. (U.K.), Forest Record no. 22, pp. 1–25
48. CAMPBELL, R. H., 1915: *Planning a tree plantation for a prairie homestead.* Can. Dep. Int., Forestry Branch, Circ. no. 5, pp. 3–8

49. CAMPBELL, R. H. & R. B. GRAU, 1948: *Evergreen windbreaks for Iowa farmsteads.* Iowa State Coll. Ames, Agric. Exp. Stat., Bull. no. 88, pp. 920–948
50. CARDER, A. C., 1961: *Rate of evaporation from a freewater surface as influenced by exposure.* Can. J. Plant Sci. *41*, 1, pp. 199–203
51. CATRINA, I., 1959: *Regional amezelii solului sub perdelele de protectie din cimpia Baraganului. (The water balance of soils under shelterbelts on the Baragan plain.)* Rev. Padurilov (U.S.S.R.) *74* (7), pp. 384–388
52. CERNIKOV, F. S., 1958: *Temperaturzyi rezum svetlokastanovoj svglinistoj Ergeney v pole i pod lenoj polosoj. (Temperature regime of light chestnut clay-loam soils of the Ergin hills in a field and under a shelterbelt.)* Pocvoved (U.S.S.R.) (4), pp. 67–73
53. CHANASYK, V. & E. C. STACEY, 1956: *Windbreaks for the Peace River region.* Can. Dep. Agric., pp. 1–11
54. CHEPIL, W. S., 1946: *Dynamics of wind erosion; VI. Sorting of soil material by the wind.* Soil Sci. (U.S.A.) *61*, pp. 331–340
55. — , 1949: *Wind erosion control with shelterbelts in North-China.* Agron. J. (U.S.A.) *41*, 3, pp. 127–129
56. CHEPIL, W. S. & N. P. WOODRUFF, 1959: *Estimations of wind erodibility of farm fields.* Kansas Agric. Exp. Stat., Res. Rep. no. 25, pp. 1–21
57. CHEYNEY, E. G., 1931: *Establishment, growth and influence of shelterbelts in the prairie region of Minnesota.* Univ. Minnesota, Univ. Farm, Bull. no. 285, pp. 3–36
58. COLEMAN, SUMMER, 1946: *A line of trees that saved the West.* Can. Forest and Outdoors *42*, 4, pp. 101–102
59. CORBY, G. A., 1955: *Airflow over mountains.* Nature *175*, no. 4453, pp. 414–415
60. CROSSLEY, D. I., 1935: *Shelterbelts for the prairies.* Forestry Chron. *11*, 1, pp. 8–19
61. CROW, F. R., 1961: *Reducing reservoir evaporation.* Agric. Engin., pp. 240–243
62. DAHL, J., 1940: *Progress and development of the prairie states forestry project.* J. of Forestry *38*, 4, pp. 301–306
63. DAUTOV, R. K., 1953: *Effect of forest shelterbelts on the depth of snow cover and soil freezing.* Dokl. Akad. Nauk. S.S.S.R. *89*, 3, pp. 555–556
64. DAVIS, E. J., 1938: *Windbreaks for Illinois farmsteads.* Illin. Dep. of Registr. and Educ., Nat. Hist. Div. Urbana, Circ. no. 29, pp. 1–18
65. DAVIS, J. F., 1945: *The effect of some environmental factors on the set of pods and yield of white pea beans.* J. of Agric. Res. (U.S.A.) *70*, 7, pp. 237–248
66. DENUYL, DANIEL, 1936: *The zone of effective windbreaks influence.* J. of Forestry *34*, 7, pp. 689–695
67. — , 1943: *Windbreaks for protecting muck soils and crops.* Purdue Univ., Agric. Exp. Stat. Lafayette (Indiana), Circ. no. 287, pp. 1–12
68. — , 1949: *Tree windbreaks for Indiana farms.* Purdue Univ. and U.S. Dep. of Agric., coop. Ext. Work, Bull. no. 226, pp. 1–16
69. DENNIS, J. S., 1922: *Shelterbelts change face of nature.* Can. Forestry Mag. *18*, p. 1199
70. DETERS, M. E. & HENRY SCHMITZ, 1936: *Drought damage to prairie shelterbelts in Minnesota.* Univ. Minnesota, Agric. Exp. Stat., Bull. no. 329
71. DORLAND, ROBERT E. & F. W. WENT, 1947: *Plant growth under controlled conditions; VIII. Growth and fruiting of the Chili pepper (Capsium annum).* Am. J. of Bot. *34*, 8, pp. 393–401
72. DOORENBOS, J., 1953: *Flowering and environment.* Sci. Horticult. *12*, pp. 44–53
73. DOUGHTY, J. L., 1944: *How to value prairie shelterbelts and hedges?* Can. Forest and Outdoors *40*, 5, p. 105
74. DURRELL, GLEW R., 1939: *Social and economic effects of the great plains shelterbelt in terms of soil and human betterment.* J. of Forestry *37*, 2, pp. 144–152

75. — , 1939: *Shelterbelts and human betterment.* Conservation *5,* 1, pp. 19–21
76. EDMOND, J. B., A. M. MUSSER & F. S. ANDREWS, 1953: *Fundamentals of horticulture.* Blakeston Comp. Inc., New York-Toronto, pp. 1–310
77. EDMONDSON, W. O., 1930: *The planting and care of shelterbelts in Wyoming.* Coll. of Agric. and U.S. Dep. Agric., coop. Ext. Work, Circ. no. 27, pp. 3–24
78. EDWARDS, C. A., 1939: *Field crop shelterbelts in western Canada.* Forestry Chron. *15,* 6, pp. 99–102.
79. — , 1948: *Tree planting and forestry practices in the prairie areas of western Canada.* Forestry Chron. *24,* 2, pp. 111–116
80. ELCHIBGOFF, I. M., 1956: *Shelterbelt in the U.S.S.R.* Am. Forests *62,* 1, pp. 30–31, 56–58
81. ELINECKIJ, L. M., 1958: *Ubedetel' nye dannye o olijanii lesnyh polos na uoosaj. (Convincing data on the influence of shelterbelts on agricultural yields).* Lesn. Hoz. (U.S.S.R.) *11,* 5, pp. 33–34
82. ERPERT, S. D., 1958: *Opyt polezascitnogo lesorazvednija na pocvah soloncovogo kompleksa. (Shelterbelt planting trials on soils of the Solonoz complex.)* Trud. Inst. Les. (U.S.S.R.) no. 38, pp. 21–40
83. ERMILOV, G. B. & D. Ya. SHREV, 1960: *Leaf productivity and plant growth in corn.* Doklady Bot. Sci. Sect. (Proc. Acad. of Sci. U.S.S.R.) *130,* 1–6, pp. 39–41
84. EVANS, J. D. D., 1953: *Shelterbelts for hill farms.* Quart. J. of Forestry *47,* 2, pp. 101–106
85. EWSEJENKO, W., 1958: *Forest shelterbelts in the Irtysh river region.* Sel'skoe Khozjaistwo Kozakstana (U.S.S.R.) *1,* pp. 83–84
86. FADEEV, A. D., 1958: *Podbov sputnikov luba v polezaszitnyh polosah. (Selection of associates for oak in shelterbelts.)* Sel'skoe Hozpapstro Polvolz' ja (U.S.S.R.) 9, pp. 35–36
87. FERBER, A. E., 1958: *Windbreaks in conservation farming.* U.S. Dep. Agric., Misc. Publ. no. 759, pp. 1–22
88. FLORELL, CIRL. & HENRY RUFLET, 1960: *Transpiration of wheat plants cultivated under different environmental conditions.* Physiologia plantorum (Copenhagen) *13,* fasc. 3, pp. 482–486
89. FLOYD, J. WHITNEY, 1940: *Tree windbreak protection for Utah farms.* Dep. Agric. Exp. Stat. at Logan, Utah (U.S.A.), new ser. Circ. no. 107, pp. 1–4
90. FREY-WYSSLING, A., 1950: *Physiology of cell wall growth.* Ann. Rev. of Plant Physiol. (U.S.A.), pp. 169–182
91. GAASTRA, P., 1959: *Photosynthesis of crop plants as influenced by light, carbon dioxide, temperature, and stomatal diffusion resistance.* Meded. Landbouwhogeschool Wageningen (Netherlands) 59 (13), pp. 1–68
92. GEIGER, R., 1957: *The climate near the ground.* Harvard Univ. Press, pp. 1–494
93. GEORGE, E. J., 1948: *Spacing distances for windbreak trees on the northern great plains.* U.S. Dep. Agric., Circ. no. 770, pp. 1–28
94. — , 1956: *Cultural practices for growing shelterbelt trees on the northern great plains.* U.S. Dep. Agric., Techn. Bull. no. 1138, pp. 1–33
95. — , 1957: *Shelterbelts and windbreaks.* Agric. Yearb., U.S. Dep. Agric., pp. 715–721
96. — , 1957: *Shelterbelts for the northern great plains.* U.S. Dep. Agric., Farmers' Bull. no. 2109, pp. 1–15
97. GEORGESCU, C. C., I. LUPE, I. CATRINA & G. MARCU, 1954: *Influensa perdelelor forestiere de protectieasupra ume zeliisolului in imediata lor apropiere. (The influence of shelterbelts on soil moisture in their immediate vicinity).* Bull. St. Acad. Repub. Rumania (sect. St. biol.) *6* (3). (Ref. no. 434 Forestry Abstr. *17,* 1956
98. GLOYNE, R. W., 1959: *Shelter problems in relation to crop and animal husbandry.* Univ. Coll. of Wales (U.K.), Mem. no. 2, pp. 1–31

99. — , 1953: *Some effect of shelterbelts upon local and microclimate.* Forestry, pp. 85–95
100. GOOR, A. J., 1959: *Informe al gobienno del Uruguay sobre cortinas protectoras y rompevientos. (Report to the Government of Uruguay on shelterbelts and windbreaks)*. Exp. Techn. Assis. Progr. FAO, Rome, Rep. no. 1079, pp. 1–16
101. GRABHORN, R., 1960: *Baumreihen als Hochwasserschutz. (Tree rows as protection against floods.)* Suppl. to Holzzucht (Reinbek, Germany) *14* (2)
102. GRACHEV, A., 1957: *Shelterbelt: Kamyshin to Stalingrad.* Stalingrad Publ. House, pp. 1–76
103. GREGORY, F. G., F. L. MILTHORPE, H. L. PEARSE & the late H. J. SPENCER, 1950: *Experimental studies of the factors controlling transpiration; II. The relation between transpiration rate and leaf water content.* J. of Exp. Bot. *1*, 1, pp. 15–28
104. GREEN, F. H. W., 1959: *Rainfall, evaporation and land use.* J. of Inst. of Water Engineers (U.K.) *13*, 7, pp. 575–580
105. GRUZDEN, D. M., 1957: *Vliganie lesnyh polos na vetrovaja eroziju pocv v zavolze. (The influence of shelterbelts on wind erosion in the Transvolga region.)* Pocvoved (U.S.S.R.) (9), pp. 116–119
106. HAFEZ, M. G. A., 1960: *Studies in stomatal behaviour. Effects of moving and still air on stomata of Eupatorium and Mentha.* Plant Psysiol. *35*, 5, pp. 651–653
107. HARING, C. T., 1942: *The shelterbelt – eight years of progress.* Univ. Washington, For. Club Quart. *15*, 3, pp. 10–14
108. HARRINGTON, F. M., 1930: *Dry-land shelterbelts tests.* Univ. Montana, Agric. Exp. Stat. Bozeman, Bull. no. 235, pp. 3–16
109. HATTON, J. H., 1936: *Before the shelterbelt.* Conservation *2*, 2, p. 7
110. HEWITT, S. P. & O. F. CURTIS, 1948: *The effect of temperature on loss of dry matter and carbohydrate from leaves by respiration and translocation.* Am. J. of Bot. *35*, 10, pp. 746–754
111. HOGG, W. H. & W. C. IBBETT, 1956: *Wind shelter for horticultural crops.* Min. of Agric., Fish. and Food (U.K.), Agriculture *72*, pp. 587–590
112. HOLT, R. F. & C. A. VAN DOREN, 1961: *Water utilization by field corn in western Minnesota.* Agron. J. *53* (1), pp. 43–45
113. HUDSON, J. P., 1957: *General aspects of environmental control.* Univ. Nottingham, 4th Easter School in Agric. Sci., pp. 159–170
114. — , 1959: *Plants and the weather.* J. of Roy. Horticult. Soc. (G.B.) *84* (10) and *84* (11), pp. 443–456, 509–524
115. HUME, J. E. & F. L. BAILEY, 1952: *Shelter in citrus orchards.* New Zealand J. of Agric. *85*, pp. 135–141
116. HUNTINGTON, ELLSWORTH, 1934: *Marginal land and the shelterbelt.* J. of Forestry *32*, 8, pp. 804–812
117. ISAAC, E. E., 1930: *Shelterbelts for Montana.* Montana State Coll. of Agric. and Mech. Arts and U.S. Dep. Agric., coop. Bull. no. 109, pp. 1–16
118. — , 1931: *Planting and care of shelterbelt trees.* Montana State Coll., Ext. Serv., and U.S. Dep. Agric., Circ. no. 15, pp. 1–4
119. IIZUKA, H., 1957: *On the standard width of seaside windbreaks.* J. of Jap. For. Soc. 39 (5), pp. 169–174
120. JENSEN, MARTIN, 1954: *Shelter effect.* Danish Techn. Press, Copenhagen, pp. 1–260
121. — , 1955: *The model law for phenomena in natural wind.* Ingeiøren (Denmark) *2*, 4, pp. 121–129
122. JOACHIM, H. F., 1957: *The establishment and evaluation of shelterbelts in Czechoslovakia.* Forestry Abstr. (U.K.) *15*, pp. 212–213
123. JOHNSON, L. P. V., 1957: *The role of natural selection in the improvement of shelterbelts trees.* Agric. Inst. Ottawa *12* (5) pp. 13–14, 36

124. KARSCHON, R. & D. HETH, 1958: *Wind speed, wind-born salt and agricultural crops as affected by wind-breaks.* La-Yaaran (Israel) *8* (3/4), pp. 8–13, 38–42

125. KHAN, MUHAMMED IHSAN-UR-RAHMAN, 1955: *The need and possibilities of establishing shelter-belts for erosion control in arid and semi-arid parts of West-Pakistan.* Pakistan J. of Forestry, pp. 150–155

126. KING, A. J., 1960: *The siting, form and maintenance of a shelterbelt for a high-lying, stock-raising hill farm.* Quart. J. of Forestry (U.K.) *54,* 4, pp. 363–366

127. KITIN, B. P., 1959: *Opitat po sazdavane na polezastitni gorski pojasi v Juzna Dobrudza. (Creation of shelterbelts in the S. Dobruja.)* Naucni Trudore, Agronomiceski Fakultet, Kss Selskostopanski Institut 'G. Dimitrov' (Bulgaria) no. 7, pp. 209–256

128. KLIMOV, V. I. & A. N. KUZJURIN, 1959: *Vyrascivanie polezascit-nyh lesnyh polos v ucebnom hozjajstreimeni Kalinina (1949–1957 gg.). (Growing shelterbelts in the Kaliniss experimental farm (Tarisbor region) in 1949–1957.)* Akad. Moskva, Izv. Timorjaz. Sel'. hoz. no. 4, pp. 121–138

129. KNOWLES, P. F., 1960: *New crop establishment.* Econ. Bot. (U.S.A.) *14,* 4, pp. 263–275

130. KOLDANOV, V. SA., 1958: *Oblesenie stefoej nasej rodinij. (The afforestation of the steppes of the U.S.S.R.)* Pririoda (Moskva) *47* (5), pp. 31–38

131. KRAAIJENGA, D. A., 1960: *Groeimetingen bij de tulpebol. (Growth measurements on the tulip bulb.)* State Agric. Univ. Wageningen (Netherlands) pp. 1–53

132. KRAEVOJ, S. JA., 1959: *O zascitnoj i podgonocnoj roli kulis iz kustarnokor i vysokostebel zijh sel' skohoz-jajstuennyh rastenij deja duba cerescatoga. (The role of strips of shrubs and fall farm crops in protecting and accelerating the growth of Quercus robeer.)* Trud. Inst. Les. (U.S.S.R.) no. 42, pp. 67–97

133. — , 1959: *K vazrabotke sposobor vyrasciranlja zascitnyh poloszyh lesonasazolenig na Ergenah. (Working out methods of growing shelterbelts in the Ergeni hills.)* Trud. Inst. Les. (U.S.S.R.) no. 42, pp. 11–66

134. KUIPER, P. J. C. & J. F. BIERHUIZEN, 1958: *The effect of some environmental factors on the transpiration of plants under controlled conditions.* Lab. Plant Physiol. Res. State Agric. Univ. Wageningen (Netherlands), 157th Commun., pp. 1–16

135. KUIPER, P. J. C., 1961: *The effect of environmental factors on the transpiration of leaves, with special reference to stomatal light response.* State Agric. Univ. Wageningen (Netherlands), pp. 1–49

136. LEONTIEVSKY, N. P., 1934: *Rol drevesnyh zashtinykh poloss r poryshen II urojainosti. (The plan of shelterbelt planting in raising the agricultural field).* J. of Geophysics *(Moscow) 4,* 1 (11), pp. 127–140

137. LETEY, J. & G. R. BLANK, 1961: *Influence of environment on the vegatative growth of plants watered at various soil moisture sections.* Agron. J. (U.S.A.) *53,* 3, pp. 151–152

138. LINDE, R. J. VAN DER & J. P. M. WOUDENBERG, 1951: *On the microclimatic properties of sheltered areas. The oak-coppice sheltered area.* Inst. Biol. Field. Res. (Arnhem, Netherlands), Meded. 10/1951, pp. 1–151

139. LINDE, R. J. VAN DER, 1953: *Some aspects of the problems of shelter in cultivated areas.* Int. Un. For. Res. Org., Proc. 11th Congr. (Rome 1953), pp. 269–280

140. LOEWEL, E. L., 1958: *Windschutz im Obstbau. (Protection of fruit trees against wind.)* Holzzucht (Reinbek, Germany) *12* (1), pp. 3–4

141. LUNEZ, G., 1953: *The climatic effects of the shelterbelts. Results of the investigation carried on in 1951.* Hung. Agric. Rev. *11,* 3, pp. 8–9

142. LUPE, I. & J. CATRINA, 1954: *Contributie la imbunatatired metodei coridorului pentru perdele de protectie. (Suggested improvements to the corrider method of designing shelterbelts.)* Bull. St. Acad. Repub. Rumania (sect. St. biol.) *6* (1), pp. 183–202

143. Lupe, I., 1957: *Contributie la cunvasterea productie de fructe in perdible de protectie a cimplui. (Fruit production in field shelterbelts.)* Rev. Padurelor (Rumania) (7), 444–448
144. Mac Donald, G. B., 1916: *Renewing the shelterbelt.* Iowa State Coll. of Agric. and Mech. Arts, Agric. Exp. Stat., Circ. no. 27, pp. 2–16
145. Mathews, Oscar, R. S. Clark & J. Verner, 1937: *Results of field crop, shelterbelt, and orchard investigations at the United States dry land field station Ardmore, S. Dak., 1911–1932.* U. S. Dep. Agric. Circ. no. 421, pp. 1–48
146. Masinskaja, L. P., 1950: *Establishing shelterbelts in vineyards.* Vinodelie i Vinogradarstvo SSSR *10* (6), pp. 22–24
147. Matiakin, G. I., 1934: *Rostashevskie zashchitnye poldsy. (Rotaski shelterbelts.)* All-Union Scient. Res. Inst. for silvic. and improvement farmland by forestation, no. 5, pp. 27–68. (transl. from Russian by U.S. For. Serv.)
148. Mazek-Fialla, K., 1958: *Organisation und Technik des Bodenschutzes (Windschutzes) in Niederösterreich. (Organization and technique of soil, soil conservation (wind protection) in lower Austria.)* Allg. Forstz. (Austria) *13* (38), pp. 537–541
149. Mc.Ardle, Richard F., 1960: *The concept of multiple use of forest and associated lands. Its values and limitations.* Unasylva *19*, 4, pp. 167–169
150. Metcalf, W., 1936: *The influence of windbreaks in protecting citrus orchards.* J. of Forestry *34*, pp. 571–580
151. Michael, D. T., 1960: *Aspects of shelter in relation to the grazing animal.* Scott. Forestry *14*, 3, pp. 130–135
152. Miller, V. J., 1960: *Temperature effect on the rate of apparent photosynthesis of seaside bent and Bermudagrass.* Proc. Am. Soc. Horticult. Sci. *75*, pp. 700–703
153. Miller, Wilhelm, 1916: *Belt planting.* Country Life in America, pp. 28–29
154. Mironov, V. V. & L. S. Savel'Eva, 1958: *Effecktivnost' lesnyh polos v bor'be s pyl-nymi burjami v stepah severnogv Kavkaza. (The effectiveness of shelterbelts against dust storms in the N. Caucasus.)* Lesn. Hoz. (U.S.S.R.) *11* (2), pp. 25–29
155. Mitchell, Archibald, 1923: *Wood crops on prairie acres.* Can. Forestry Mag. *19*, 2, pp. 104–106
156. Mitchell, John W. & Paul C. Marth, 1950: *Growth regulating substances in horticulture.* Ann. Rev. of Plant Physiol. (U.S.A.), pp. 125–140
157. Moss, Dale N., Robert B. Musgrave & Edgar R. Lemon, 1961: *Photosynthesis under field conditions; III. Some effects of light, carbon dioxide, temperature, and soil moisture on photosynthesis, respiration, and transpiration of corn.* Crop Sci. (U.S.A.) *1*, 2, pp. 83–87
158. Munns, E. N. & J. N. Stoeckeler, 1946: *How are the great plains shelterbelts?* J. of Forestry *44*, 4, pp. 237–257
159. Munns, E. N., 1947: *Shelterbelts are more than trees.* Am. Forests *53*, 6, pp. 248–250, 284
160. Nägeli, W., 1943: *Untersuchungen über die Windverhältnisse im Bereich von Windschutzstreifen.* Mitt. Schweiz. Anst. forstl. Versuchswes. *23*, pp. 221–276
161. —, 1946: *Weitere Untersuchungen über die Windverhältnisse im Bereich von Windschutzstreifen.* Mitt. Schweiz. Anst. forstl. Versuchswes. *24*, pp. 659–738
162. —, 1953: *Untersuchungen über die Windverhältnisse im Bereich von Schilfrohrwanden.* Mitt. Schweiz. Anst. forstl. Versuchswes. *29*, pp. 213–266
163. —, 1957: *Report to the Government of Israel on shelterbelts and windbreaks.* Exp. Techn. Assis. Progr. FAO, Rep. no. 586, pp. 1–27
164. Nagle, John P. & James W. Stubbs, 1940: *The farm windbreak for eastern Washington.* State Coll. of Washington, Ext. Serv. pp. 1–4
165. Nelson, A. L., 1931: *Shelterbelts and fruits.* Univ. Wyoming, Agric. Exp. Stat. Laramie, Bull. no. 179, pp. 3–21

166. Nicota, B., 1957: *Dejstroto na polezastitnite sumski pojasi vo namaluvanje brzinata na veterot. (The effect of shelterbelts on reducing wind speed.)* Godisn Sum. Inst. Skopje *2* (1), pp. 3–44
167. Nichiporovich, A. A., 1958: *Photosynthesis and the theory of obtaining high yields.* A book review. Translation by Inst. of Biol. Sciences of Russian Plant Physiology (Fiziologiia Rastezii) *5*, 1, pp. 88–91
168. Overbeek, J. van, 1956: *Absorption and translocation of plant regulators.* Ann. Rev. of Plant Physiol. (U.S.A.) *7*, pp. 355–372
169. Paramonov, A.Ja., 1957: *Effektivnost' polezascitnyh lesnyh polas v SSSR. (The efficiency of shelterbelts in the U.S.S.R.)* Vestnik Inst. po Izuceniju SSR no. 2 (23), pp. 1–23
170. Pardy, A. A., 1949: *Windbreaks and shelterbelts.* Rhodesia Agric. J. *46*, 2, pp. 65–72
171. Panfilov, Ya., 1935: *O Konstruktsii Lesnykh polos. (The influence of shelterbelts.)* J. of Na Lesokulturnom Fronte (On Silvicultural Front), Moscow, no. 7–8, pp. 2–18
172. — , 1936: *Shelterbelts.* All-Union Res. Inst. for agri-forestry melioration and forest management (Moscow), no. 6
173. — , 1940: *A contribution to the problem of the effect of shelterbelts on wind velocity on steep slopes.* Sovetsk. Agron. (10), pp. 11–17
174. Pavlovskij, E. S., 1960: *Diagonal nogruppovoj sposob posadki lesnyh polos. (A diagonal-group method of laying-out shelterbelts.)* Vestn.Sel' -hoz. Nauki (Moskva), *5* (5), pp. 120–123
175. Peat, E. J. & K. J. Brown, 1960: *Effect of management on increasing crop yields in the Lake Province of Tanganyika.* East African Agric. and Forestry *26*, 2, pp. 103–105
176. Pis'mennyj, N. R., 1960: *Sistema lesnyh polosnadeznaja zascita ot pyl'nyh bur'. (Shelterbelt networks, a reliable protection against dust storms.)* Lesn. Hoz. (U.S.S.R.) *12* (7), pp. 23–28
177. Ramsey, Guy R., 1936: *Evergreen windbreaks for Iowa farmsteads.* Iowa State Coll., Ext. Circ. no. 217, pp. 1–32
178. Read, Ralph A., 1957: *Effect of livestock concentration on surface soil porosity within shelterbelts.* J. of Forestry *55*, 7, pp. 529–530
179. — , 1958: *The great plains shelterbelt in 1954.* Rocky Mountain Forest and Range Exp. Stat., Bull. no. 441, pp. 1–95
180. Relords, Percy C., 1913: *Tree planting for shelter in Minnesota.* Minnes. Forestry Board, Forest Serv. Bull. no. 1, pp. 6–30
181. Renshaw, E. W., 1936: *The plains shelterbelt.* Idaho Forester *18*, pp. 13–16
182. Rhee, J. A. van, 1959: *Windbeschutting van cultuurgewassen, vooral onderzocht voor fruit. (Wind protection of agricultural crops, especially studied on fruit).* Inst. Biol. Field Res. (Arnhem, Netherlands), 43/1959, pp. 1–66
183. Rider, N. E., 1952: *The effect of a hedge on the flow of air.* Quart. J. of Royal Meterol. Soc. (U.K.) *78*, 335, pp. 97–101
184. Rigdon, Harry P., 1944: *Windbreaks and their relations to agriculture.* Oklahoma Agric. and Mech. Coll. and U.S. Dep. Agric., Circ. no. 398, pp. 3–14
185. Ross, Norman M., 1920: *What to plant for prairie tree-shelters, with tables showing how fast various trees attain good height.* Can. Forestry J. *16*, pp. 223–226
186. Runge, E. C. A. & R. T. Odell, 1958: *The relation between precipitation, temperature and the yield of corn on the Agronomy South Farm, Illinois.* Agron. J. 8, pp. 448–454
187. Rutherford, J. G., 1922: *Shelterbelts on prairie farms; stock can live in the open all year round if tree shelter is provided.* Can. Forestry Mag. *18*, pp. 1068–1070
188. Said, Muhammad 1954: *Effects of shelterbelts on soil moisture.* Pakistan J. of Forestry *4*, 3, pp. 175–179
189. — , 1954: *Shelterbelt work in some of the countries of the world.* Pakistan J. of Forestry *4*, 2, pp. 81–91

190. Schultz, Herbert T. & Alan B. Carlton, 1959: *Field windbreaks for row crops.* California Agric. *13,* 11, pp. 5–6

191. Schwabe, W. W., 1957: *The study of plant development in controlled environments.* Proc. Univ. Nottingham, 4th Easter School in Agric. Sci., pp. 16–35

192. Scruton, C., 1961: *Wind tunnels and flow visualization.* Nature *189,* no. 4759, pp. 108–110

193. Schaffer, H. G., 1960: *Shelterbelts can minimize risks of crop damage.* Commerc. Grower (U.K.), pp. 927–928

194. Seaton, H. E., 1947: *Trees in farm economy.* Town and Country Planning *15,* 57, pp. 30–31

195. Selivanov, G. I., 1960: *Iz opyta rubok uhoda v zascitnyh nasazden-ija. (Thinning trials in shelterbelts.)* Lesn. Hoz. (U.S.S.R.) *12* (3), pp. 26–29

196. Shah, Syed Riaz Hussain, 1959: *The United States shelterbelt programme and its possible adaptation to West-Pakistan.* State Univ. of New York, Coll. of Forestry at Syracuse (U.S.A.), pp. 1–161

197. — , 1960: *Economic analysis for the establishment of shelterbelts project in West-Pakistan.* Agric. Pakistan *11,* 3, pp. 465–473

198. — , 1960: *Shelterbelts: An asset to the nation.* Agric. Pakistan *11,* 4, pp. 526–539

199. — , 1961: *The influence of excessive rainfall on the protective value of windscreens with respect to crop yields.* Netherl. J. of Agric. Sci. *9,* 4, pp. 262–269

200. Shaw, Elmar W., 1957: *A new look at shelterbelts.* Am. Forests *63,* 12, pp. 18–19, 47–49

201. Shiptchinsky, A. W., 1926: *Vlianie na klimat zashtitnykh poloss v kamennoi stepi. (The climatic influence of shelterbelts in the Kamennaya steppe, District of Voronezh.)* Rep. Voronezh Agric. Inst. *5,* pp. 34–59 (Transl. from Russian by the U.S. Forest Serv.)

202. Shulley, F. J., 1945: *The Arkansas shelterbelt.* J. of Forestry *43,* 1, pp. 25–26

203. Singleton, R. C., 1937: *Shelterbelt.* Conservation *3,* 4, p. 9

204. Silcox, F. A., 1935: *Forest Service favour shelterbelt.* Forestry News Digest, p. 5

205. Sims, H. J., 1946: *The effect of shelterbelts on wind velocity.* Austral. J. of Sci. *8,* 1

206. Smal'Ko, Ja. A., 1960: *Vetrozascit-nye srojstra lesnyh polos v zarisimasti ot bormy ih poperecnoga secenija. (The protective properties of shelterbelts in relation to their cross-sectional shape.)* Lesn. Hoz. (U.S.S.R.) *12* (9), pp. 27–30

207. Smirnov, N. P., 1958: *Opyt polejascitnogo lesorazvedneija. (A shelterbelt planting trial.)* Zemlechelie (Moskva) 6 (a), pp. 40–47

208. Smith, L. F., 1940: *Windbreaks for Kansas farmsteads.* Kansas State Coll. of Agric. and Appl. Sci. Ext. Serv., Circ. no. 140, pp. 1–32

209. Smith, Michal, 1959: *The survey of derelict land.* J. of the Town Planning Inst. (U.K.) *45,* 2, pp. 38–40

210. Smolik, L., 1947: *Vliv vetrolamu na vypar v oblasti jizni Moravy. (The influence of windbreaks upon evaporation in S. Moravia.)* Sbornik Ceskoslov. Akad. Zemedelski 19, pp.1–3

211. Sneesby, Norman J., 1953: *Wind erosion and the value of shelterbelts.* Agric. J. (U.K.) *60,* 6, pp. 263–271

212. Sprague, George F., 1955: *Corn and corn improvement.* Academ. Press Inc. (New York), pp. 1–689

213. Stanhill, G., 1958: *Evapo-transpiration from different crops exposed to the same weather.* Nature *182,* no. 4628, p. 125

214. Stevenson, Frank V., 1951: *Internal damage to celary in Florida caused apparently by winds of hurricane force.* U.S. Dep. Agric., Plant Disease Reporter *35,* 9, p. 402

215. Stewart, Norman, 1957: *Fruit cultivation: Combating storm damage.* Gardeners Chron. (London), *142,* pp. 118–119

216. Stoeckeler, J. H. & C. G. Bates, 1939: *Shelterbelts: The advantages of porous soils for trees.* J. of Forestry *37,* 3, pp. 205–221

217. Stolp, D. W., 1960: *Plant and moisture relationships with vegetable crops in a light sandy soil.* Versl. Landbouwk. Onderz. (Wageningen, Netherlands) 66.16, pp. 1–235
218. Sun, C.-S. & C. N. Liu, 1959: *Establishing shelterbelt on canal irrigation systems in the central basin of the Hwang Ho river.* For. Sci. (Peking) 5, pp. 370–380
219. Swenson, W. S., 1957: *Squawbusch in windbreaks in eastern Colorado.* J. of Soil Water Conserv. (U.S.A.) *12* (4), pp. 184–185
220. Tamate, S., 1956: *Influence of windbreaks on evaporation.* Proc. Cong. Int. Un. For. Res. Org., Oxford, sect. 1, no. 7
221. — , 1956: *Effect of windbreaks on the decrease of salt content in seawind.* Proc. Congr. Int. Un. For. Res. Org., Oxford, sect. 11, no. 8
222. Taylor, K. W., 1939: *Shelterbelts as recreation areas and game refuges.* Parks and Recreation (U.S.A.) *22*, 7, pp. 352–367
223. Telesek, Ju. K., 1960: *Vetrozasci-tnoe znacenie lesnyh polos na melosvjaznyh pocvah. (The importance of shelterbelts for wind protection on soils of poor cohesion.)* Vestn. Sel.'-hoz. Nauki (U.S.S.R.) *5*, (7), pp. 107–110
224. Tinker, E. W., 1938: *What's happened to the shelterbelt?* Conservation *4*, 1, pp. 14–16
225. Todorov, T. & D. Blaskova, 1959: *Varlu rlijanieto na polezastitnite gorski projas na mekroklimata. (The influence of shelterbelts on the microclimate.)* Naucni Trudore, Agronomiceski Fakultet, viss selskostopanski Institut 'G. Dimitrov' (Bulgaria) no. 6, pp. 103–152
226. Traven, F. I., 1958: *Polezascitnoe lesorozvedenie v bov'be s vetrovoj eroziej. (Shelterbelt planting to control wind erosion.)* Zemledelie (Moskva) 6 (a), pp. 47–52
227. Trenk, Fred. B., 1927: *Windbreaks and shelterbelts for Maryland.* Univ. Maryland, pp. 1–39
228. — , 1938: *Shelterbelts for windblown soils.* Univ. Wisconsin, Wisconsin Coll. of Agric., Ext. Serv. Circ. no. 287, pp. 1–6
229. — , 1939: *The farm windbreak.* Wisconsin Coll. of Agric., Ext. Serv. Circ., pp. 1–8
230. Trenk, F. B. & A. R. Albert, 1955: *Growth and effectiveness of allconifer and mixed hardwood conifer shelterbelts on plain field sand.* Wisconsin Coll. of Agric., For. Res. Note no. 23, pp. 1–2
231. Vlasov, S. I. & N. M. Zajcev, 1959: *Zascitnye lesonasazdenija v orosaemyh uslovijah prikaspijskoy nizenennosti. (Shelterbelts in the irrigable areas of the Cis-caspian lowland.)* Trud. Inst. Les. (U.S.S.R.) no. 42, pp. 98–131
232. Vyssorsky, G. N., 1935: *Shelterbelts in the steppes of Russia.* J. of Forestry *33*, 9, pp. 781–788
233. Wadworth, R. M., 1959: *An optimum windspeed for plant growth.* Ann. of Bot., new ser. *23*, 89, pp. 195–200
234. — , 1960: *The effect of artificial wind on the growth rate of plants in water culture.* Ann. of Bot., new ser. *24*, 94, pp. 200–211
235. Walker, John, 1945: *Pruning, thinning and utilizing trees. With special reference to prairie farm shelterbelts.* Can. Dep. Agric., Publ. no. 770, Circ. no. 176, pp. 3–6
236. — , 1946: *Planning and planting field shelterbelts.* Can. Dep. Agric., Publ. no. 785, Bull. no. 139, pp. 5–15
237. Wallace, L. Fons, 1940: *Influence of forest cover on wind velocity.* J. of Forestry *38*, 6, pp. 481–486
238. Wassink, E. C., 1948: *Photosynthesis.* Ann. Rev. of Biochem., pp. 559–578
239. — , 1957: *The study of plant growth in controlled environments.* Proc. Univ. Nottingham, 4th Easter School in Agric. Sci., pp. 36–57
240. Wellensiek, S. J., 1957: *The plant and its environment.* Proc. Univ. Nottingham, 4th Easter School in Agric. Sci., pp. 3–15
241. — , 1960: *Stem elongation and flower initiation.* Landbouwhogeschool Wageningen (Netherlands), Lab. Tuinbouwplantenteelt, Publ. no. 204, pp. 159–166

242. — , 1960: *Flower formation in Campanula medium.* Landbouwhogeschool Wageningen (Netherlands), Lab. Tuinbouwplantenteelt, Publ. no. 205, pp. 1–18

243. WENT, FRITS W., 1957: *The experimental control of plant growth.* Chronica Botanica Comp., Waltham (Mass., U.S.A.), pp. 194–324

244. WESTVELD, R. H., 1936: *Tree windbreaks for Missouri farms.* Univ. Missouri, Coll. Agric., Ext. Serv., Circ. no. 343, pp. 1–7

245. WHITEHEAD, F. H., 1957: *Wind as a factor in plant growth. Control of the environment.* Proc. Univ. Nottingham, 4th Easter School in Agric. Sci., pp. 84–95

246. WIJK, W. R. VAN & A. P. HIDDING, 1955: *Onderzoek over de verandering van het klimaat achter windschermen. (Investigation about the alteration of the climate behind windscreens.)* Landbouwk. T. (Netherlands) *67*, pp. 707–712

247. WILLIAMS, L. A., 1941: *Recreation of the plains.* Parks and Recreation *46*, 6, pp. 62–65

248. WILLIAMS, R. A., 1945: *A quarter-billion trees against the wind.* Timberman *46*, 6, pp. 62–63, 65

249. WILLIAMS, ROSS, 1949: *Trees that beat the blizzard.* Am. Forest *55*, 8, pp. 26–27, 42–43

250. WILSON, ROBERT, 1929: *Spacing for shelterbelt plantations on the northern great plains.* J. of Forestry *27*, 3, pp. 299–301

251. WILSON, J. WARREN & R. M. WADSWORTH, 1958: *The effect of wind speed on assimilation rate: A re-assessment.* Ann. of Bot., new ser. *22*, 86, pp. 285–290

252. WILUSZ, Z., 1958: *Wplyw zadrzerwienia ochronnega na gospodarke wodna i plonowa nie przyleglyck terenow. (The effect of windbreaks on the water economy and area yield of neighbouring land.)* Ekologia Polska (Warszawa) 6a (1), pp. 1–58

253. WIT, C. T. DE, 1958: *Transpiration and crop yields.* Versl. Landbouwk. Onderzoek, 64.6, pp. 1–88

254. WOODRUFF, N. P., 1954: *Shelterbelt and surface barrier effects on wind velocities, evaporation, house heating and snowdrifting.* Kansas State Coll. of Agric. and Appl. Sci., Agric. Exp. Stat., Tech. Bull. no. 77, pp. 5–27

255. WOODRUFF, N. P., R. A. READ & W. S. CHEPIL, 1959: *Influence of a field windbreak on summer wind movement and air temperature.* Kansas State Univ. Coll. of Agric. and Appl. Sci., Agric. Exp. Stat., Tech. Bull. no. 100, pp. 1–24

256. WOOLEY, JOSEPH T., 1961: *Mechanism by which wind influences transpiration.* Plant Physiol. *36*, 1, pp. 112–114

257. WYGANT, N. D., 1938: *The relation of insect to shelterbelt plantations in the great plains.* J. of Forestry *36*, 10, pp. 1011–1018

258. YUSHKEVICH, N., 1946: *Tree shelterbelts on subtropical plantations.* J. of Forestry *44*, 3, pp. 206–207

259. ZEMLSANICKIJ, L. J., 1959: *Vlijanie lesnyh polos na porysenie plodorodija solancevatyh kastanovyh pocv. (The influence of shelterbelts on the increase in fertility of solonetz chestnut soils.)* Vestn.Sel'-Hoz. Nauki (Moskva) *4* (12), pp. 65–70

260. ZON, RAPHAEL, 1935: *Possibilities of shelterbelt planting in the plains region.* U.S. Forest Serv., p. 3

261. — , 1935: *Shelterbelts - futile dream or workable plan?* Science (U.S.A.) *81*, no. 2104, pp. 391–394

262. — , 1935: *Shelterbelts.* Conservation *1*, 1, p. 6

263. ZUKOWSKI, A. A., 1950: *Afforestation and Soviet agriculture.* Timber News *58*, no. 2130, pp. 149–151