Netherlands Journal of Agricultural Science 39 (1991) 149-164

Weather indices of agricultural production in the Netherlands 1948-1989. 1. General methodology and the arable sector

A. J. OSKAM

Department of Agricultural Economics, Wageningen Agricultural University, P.O. Box 8130, NL 6700 EW Wageningen, Netherlands

Received 15 January 1991; accepted 10 May 1991

Summary

This paper starts with the methodology of deriving weather indices for different types of agricultural production. These indices should be useful for economic research. The methodology applied to the arable sector covers the period 1948-1989. Twelve products are included. At an aggregate level most extreme variations in weather indices are less than 23 %. In the long term, systematic developments of yields are more important than weather although there are substantial differences between individual crops. Average yield increase per year is 1.3 %. The annual standard deviation due to weather is 6 %. Although the influence of weather is slightly decreasing in a relative sense, the levels of yield fluctuations are still increasing.

Keywords: weather indices, arable crops, yield fluctuations

Introduction and general methodology

For several types of research, the availability of an indicator about past weather conditions can be very useful. We will concentrate on the need for weather indices in economic research. A weather index is an aggregate quantitative indicator of weather conditions. For different types of research, however, different indicators may be relevant. Here we will direct our attention to quantitative economic research, using annual observations of output(s), inputs, prices and technology. Weather can be an important disturbing factor in explaining relations between these variables. More specific examples of the usefulness of weather indices are:

1. Productivily analysis and the measurement of technological change. Because productivity measures and indicators of technological change are highly influenced by weather conditions, productivity measures over short periods are unreliable. Extreme weather conditions at the beginning and end of even longer periods have an influence on productivity measures (Oskam, 1991). Therefore, a relevant weather index can improve considerably the measurement of technological change.

2. Estimation of production functions. Here the same arguments used for technological change can be applied. The estimated coefficients of a production function can be influenced by weather conditions. When input levels are independent of the weather, estimated coefficients of input variables will be unbiased. Yet, the uncertainty of coefficients can be still much higher without a variable representing changes of weather conditions. Moreover, the coefficient of the technology variable(s) can be biased and is less reliable without adding a weather index in the estimation procedure.
3. Estimating supply functions for agricultural outputs and/or demand relations for agricultural inputs. Supply functions give the relation between quantity of supply and output prices, input prices and technology; this type of analysis is called supply analysis. Here the same reasoning used for production functions is applicable. Time-series cross-section analysis for relative short periods, in particular, has an urgent need to eliminate the effects of fluctuating weather conditions (Thijssen, 1989).
4. In general, every agricultural sector model can be improved by adding reliable weather indices as exogenous variables (Cromarty, 1959; Oskam, 1987; Oskam et al., 1989).

These reasons are sufficient to look for reliable weather indices at the level of specific crops, subsectors of the agricultural sector or the whole sector.

Several approaches can be used. A good overview of methodology deriving weather indices has been given by Stallings (1960, 1961), Shaw (1964) and Doll (1967). The applicability of a particular approach depends also on the availability of data. Here we will give attention to three different methods to construct weather indexes, bearing in mind that an ideal weather index for a particular function consists of an index variable, which contains all the direct and indirect weather effects influencing this function. Direct effects have a direct influence on the particular function. Indirect effects result from adjustments as in the use of inputs due to different weather conditions. An example can be instructive. Assume that above some minimum level, rainfall during the growing season of sugar beets has no effect on the sugar production per hectare, while sunshine has a positive effect. The particular weather index describing the production of sugar per hectare will be influenced by sunshine and by rain up to some level. Such an index variable can be used to explain productivity or production per hectare and also for supply analysis. However, describing the number of working hours and machinery hours per unit of product, rain may have a negative effect, while sunshine is unimportant unless rainfall is high. A relevant weather index for the description of the number of working hours per unit of sugar differs from the previous one. This implies that even a constructed weather index for a particular product can be used only selectively. Although different weather indexes might be useful, we will construct *one* index only to simplify matters.

Literature on constructing weather indexes or incorporating weather influences outlines the following main lines:

1. Constructing a particular index by means of weather variables such as temperature, rainfall, and sunshine or more direct variables such as soil moisture and

radiation. Here the period of the year can also be a very important variable. The particular relation between weather variables and the resulting yield level will be estimated by means of regression analysis (Doll, 1967). A related method is to incorporate directly weather variables in an economic model (Oury, 1965, 1966) that allows to include interaction between weather variables and 'economic' variables.

2. Using the yield levels of variety trials and other experimental fields. A direct construction of weather indices can be applied. When these fields are operated under constant conditions, all differences arise from weather (Stallings, 1960, 1961). Sample fields often have different objectives, and this implies a particular development in yields that can be represented by trend variables (Stallings) or by using moving averages (Shaw, 1964). When data of field experiments are only available for a part of the period, a relation between yields and weather variables can be estimated. A functional relation that will be constant in time can be extrapolated.
3. Dividing time series of revenues in a systematic and a stochastic part. By assumption, the stochastic part has been caused by weather variation (and related variables, such as diseases and plagues), while the systematic part is related to technical development and systematic (economic) factors.

Each method has a number of difficulties. However, data availability and main factors influencing quantity variation determine which method is most useful. For the arable sector method 3 will be used. In a consecutive paper for grassland methods 2 and 3 are applied (Oskam & Reinhard, 1992). Each method will be explained before its application with special emphasis given to difficulties and biases of each method (see Sections 'Methodology' and 'Discussion'). After the presentation of the empirical results the resulting systematic parts and weather indices will be discussed.

Methodology of constructing weather indices for arable products and the arable sector

This method uses average annual yield data for particular arable products. The main assumption is that variation in yields originates from two different sources:

- A systematic part containing all variables such as technical development, use of inputs, increasing of decreasing area with differences in potential yield, etc.
- A stochastic part, mainly caused by variation of the weather among the different years.

Because data of average yields of arable crops are readily available, this method is easy to apply.

Here we assume that the yield per hectare (Y) for a particular arable product depends on a weather index (W) and a vector of other variables (x):

$$Y = f(W,x) \qquad (1)$$

Under the assumption that the function is separable in W and x and f is linear homogenous in W, the following holds (Chambers, 1988):

$$Y = W \cdot \mathrm{f}(1,x) = W\mathrm{f}_1(x) \qquad (2)$$

Here $\mathrm{f}_1(x)$ is the systematic part of the yield while W is the stochastic part. This specification implies a multiplicative model with a higher yield variation for increasing systematic yields. Next, we make the assumption that the systematic part can be represented by an exponential polynomial trend function:

$$Y = e^{\mathrm{g}(T)}.W \qquad (3)$$

Where $\mathrm{g}(T)$ is a polynomial trend function. A logarithmic transformation of (3) gives:

$$\ln Y = \mathrm{g}(T) + \ln W \qquad (4)$$

Take μ equal to $\ln W$, specify the function g, and weather index W can clearly be derived from a linear regression on:

$$\ln Y = \mathrm{g}(T) + \mu \qquad (5)$$

where, by assumption, μ is a stochastic disturbance with expectation zero, a constant variance and no covariances between the elements of different years. The weather indexes can be derived from the estimated values of the disturbances μ.

The empirical analysis uses a third degree *orthogonal* polynomial:

$$\ln Y = \alpha_0 + \alpha_1.T + \alpha_2.T^2 + \alpha_3.T^3 + \mu \qquad (6)$$

where T is a trend variable with an average value of zero during the total period. T^2 is the squared values of T, while T^3 has been transformed in such a way that the variable is orthogonal to T and T^2 (Murdoch, 1966, p. 34). The α's are the parameters of the systematic part.

Such a polynomial gives enough flexibility to allow differences in the systematic development during the period without adjusting excessively the estimated systematic part to extreme weather conditions. The parameters α_1, α_2 and α_3 are tested by means of a Student t-test. When the t-value, relative to 0, is smaller than 1.5, for these parameters, the particular explanatory variable will be deleted. This is based on the prediction criterium used by Amemiya (1980, p. 334). The unconditional mean square prediction error forms the basis of this criterium.

As a result this method gives two output series:

1. The systematic or expected yield level for that product. This yield can be derived from (6) by setting $\mu = 0$ and using the estimated α's.
2. Weather indices for the particular product; this weather index is derived from:

$$W = e^{\mu} = Y/\exp[\hat{\mathrm{g}}(T)] \qquad (7)$$

where $\hat{\mathrm{g}}(T)$ is the estimated value of the polynomial trend function.

W can be rescaled so that the average index is 1.0 during the observation period; this implies 'average' weather during that period. However, rescaling prevents that actual yield levels can be 'revealed' exactly from expected yield and the weather index without using the rescaling factor.

An additive model

As an alternative for the multiplicative model in (2), an additive model can be used. The equivalent formulation of Equation (5) is:

$$Y = \mathrm{h}(T) + \theta$$

where $\mathrm{h}(T)$ is also an orthogonal polynomial trend function and θ is the disturbance of a linear regression equation with expectation zero and a constant variance. For an increasing systematic yield, such a model implies a smaller percent variation in yields. Here the systematic yield equals the estimated value of the polynomial trend ($\hat{\mathrm{h}}(T)$), while the weather index is equal to $Y/\hat{\mathrm{h}}(T)$.

Testing between these two different models can be done by means of testing the heteroscedasticity of the disturbances μ and θ for two subperiods (Judge et al., 1980, p. 131). The model with the smallest indication of heteroscedastic disturbances gives the best description of yield variation.

Additional observations and the revision of weather indices

The methodology introduced implies that a particular weather index should be revised over the complete observation period when new observations are available. The reason is that the trend function is estimated over the total period while also the average weather index over the total period is equal to 1.0. This can be rather cumbersome in practice. Therefore, a slightly different methodology will be used with constant weather indices over a historical period (here 1951-1985) while the weather index and the systematic yield for additional years can be revised with new observations. Due to the use of third degree polynomials yield changes at the end of an observation period can have large influences at the beginning of the observation period.

Empirical analyses show mostly that only indices for the first and last two or three years show some effect of increasing the length of the period. Therefore, we have estimated the trend function over the period 1948-1989 and we have gauged the average weather index at 1.0 over the period 1951-1985. Additional observations will only change the indices after 1985.

Aggregation of weather indices

The analysis for individual crops gives weather indices and normal yield levels for individual crops. We aren often interested in weather indices at a more aggregated level, such as for grains, potatoes or even for the whole arable sector. These weather indices will be constructed by means of weighing indices for particular products. Because the weather indices will be used for economic analyses, aggregation will be based on 'normal' value shares. Using the following definition:

$$V_{i,t} = \sum_{j=-b}^{b} p_{i,t+j} \cdot q_{i,t+j} \tag{9}$$

where: V is the normalized value of a product (product i in year t), p is the price of a product, q is the quantity of a product.

The value share for an individual product i in period t ($s_{i,t}$) is derived from:

$$s_{i,t} = V_{i,t}/(\sum_{i=1}^{n} V_{i,t}) \tag{10}$$

Here we assume a total of n different products. These value shares have been used to derive aggregate weather indices. For some products (e.g. fodder crops), prices were not available. Here we assumed that an average hectare of fodder crops had the same revenue level as an average hectare of other crops.

Influences of prices and quantities in particular years will be smoothed by averaging over a period of five years ($b=2$ in Equation (9)). The five-year period has been shifted in the beginning and the end of the observation period.

Results of the empirical analysis

Table 1 gives the yield levels, which form the input for the empirical analysis.

The empirical analysis and the tests resulted in a set of normal yield functions are stated in Table 2, where one can find information on the type of function and the remaining parameters. Only two products (oats and pulse crops) show a complete third degree polynomial. These changes in systematic yield developments could be due to shifts in the areas of these products. The systematic share in the first and the second part of the period and the total period is also shown in Table 2. For eleven of the twelve products the systematic variance was more than 50 per cent of the total variance during the total period.

Table 3 shows the resulting weather indices for twelve products. All indices have an average value of 1.0 over the period 1948-1985. This implies the assumption of average weather over that particular period.

Table 4 shows aggregated weather indices for a number of products and the total arable sector. Two different indices for the arable sector have been calculated: the first excludes fodder crops (fodder beets and silage maize), while the second includes these products. Because an important share of the fodder crops is grown on mixed farms and specialized dairy farms the first index represents more the weather conditions at specialized arable farms. However, differences are small because weather indices are correlated (see also Table 6). Moreover, the share of fodder crops is always less than 17 %, although this share increased during the period 1948-1989. There are no observations for silage maize before 1954.

Table 1. Production (in kg ha[-1]) of arable farm products.[1]

Year	Wheat	Barley	Oats	Rye	Potatoes		Sugar[2]	Pulse crops	Rape seed	Flax[3]	Fodder beets	Silage maize[4]
					ware	starch						
1948	3230	2510	2230	2080	25900	27800	7249	1460	2100	8130	63900	–
1949	4410	4000	3270	2830	24600	30500	6991	3020	2430	9090	58600	–
1950	3309	3350	2710	2400	23600	26600	6916	2780	1400	7650	61500	–
1951	3740	3110	3200	2850	23500	27100	5961	2750	1910	7390	51700	–
1952	4059	3330	3160	2700	27100	27200	7276	3000	2390	8100	62400	–
1953	3959	2610	3100	2510	24800	24000	7139	2520	2260	7340	65700	–
1954	3870	3300	3270	3080	24400	25600	5959	2590	2710	7690	61100	8100
1955	3859	3759	3409	3020	26900	28000	6973	3300	2530	8290	71000	10100
1956	3800	3690	3160	2880	24500	22300	5725	2060	2510	7540	56600	7900
1957	4240	4050	3180	2910	28200	28500	6630	3230	2530	7860	70200	9500
1958	3959	3890	3240	2960	29000	24500	7568	3100	1970	7969	80600	10600
1959	4620	3680	2550	2680	22000	26500	5794	3270	2900	7290	37800	10100
1960	5010	4220	3390	3030	28500	31000	7928	3659	2700	8470	85000	9400
1961	3950	3780	3509	2520	28500	29500	7189	3330	2510	8220	75900	9000
1962	5030	4340	3900	3180	30500	32500	6307	3959	2500	8160	62100	7600
1963	4480	3859	3780	2970	28500	30500	6513	3040	2520	8280	68900	8300
1964	5010	4330	4090	3370	32500	34500	8232	3380	2840	8280	80400	9400
1965	4550	3800	3620	2550	28500	23500	6635	2600	2590	7990	57800	8700
1966	4280	3459	3600	2570	32500	31000	6440	2350	2600	7140	66000	9600
1967	5100	4200	4100	3300	37500	35500	7878	3900	2900	8630	82500	11200
1968	4700	3600	4200	3200	34000	35000	7375	3000	2700	8150	83000	9700
1969	4700	3900	3900	3300	33000	31500	7808	3100	2000	7980	81000	9800
1970	4900	3100	3700	3000	35500	35500	7234	3000	2900	6440	77500	11200
1971	5200	3700	4600	3500	37500	37500	8232	3100	3150	8850	80000	10900
1972	4400	4100	4200	2800	38000	37000	7128	2350	3000	9100	76500	8900
1973	5400	4200	4400	3400	36800	37000	7267	2850	2650	8200	75000	10000
1974	6000	4200	5000	3500	38500	40000	6930	3200	3250	8300	75500	10300
1975	5100	4000	4600	3500	32900	33500	6742	3000	2600	6400	71500	12400
1976	5700	4200	4100	3100	31000	28000	7161	2300	2800	6000	67500	8500
1977	5400	4300	4500	3500	33700	35000	7347	3100	2750	7600	79000	11200
1978	6800	4900	5600	4000	37300	40000	7759	3200	2450	8300	81000	12300
1979	6100	4500	5200	4000	36000	40000	7253	3300	2650	7950	79000	12200
1980	6400	4600	5200	4000	38000	33000	7742	2700	3600	7650	81000	12000
1981	6900	4500	5400	3800	39900	38000	8478	3400	3400	8200	89000	13900
1982	7600	5700	5700	4500	41100	32000	9341	4100	3100	7900	92500	13400
1983	7100	4500	4500	3900	34100	31500	7207	3900	2800	6550	78500	12500
1984	7900	5300	4800	4300	42700	40000	8153	4600	2850	9050	81500	10900
1985	6700	5000	5200	4200	43200	41000	7808	3650	3050	8250	84500	11500
1986	8100	6200	6100	4900	44400	35000	9576	5200	3450	7900	86500	13500
1987	7000	5200	5200	4200	46000	43500	8532	3650	3200	8050	87500	11000
1988	7400	4700	4600	4300	42400	41000	8938	3900	3300	7200	89000	13000
1989	7700	4800	4100	5000	41500	41000	9672	4500	3650	6050	91500	13500

[1] All data have been used from LEI/CBS, Landbouwcijfers, several years. Data on sugar content are partly from Maandblad Suikerunie, several years.

[2] Sugar beets have been calculated in kilogram sugar per hectare.

[3] Flax has been based on both linseed and flax.

[4] Yields of silage maize over the period 1954-1978 are derived from te Velde (1984, p. 332). Here a factor of 0.76 has been used to reduce the yields of RIVRO cultivars to actual yields of silage maize in the Netherlands. Silage maize is in kilogram of dry matter per hectare.

Table 2. Estimation results of the systematic yield function; 1948-1989.

Product	Type of function	Parameters			Average share in arable production (%)	Share of systematic variance in total variance		
		α_1	α_2	α_3		1948-1968	1968-1989	total period
Wheat	log	0.019 (0.001)[1]	0.00021 (0.00010)	–	14.1	0.503	0.687	0.890
Barley	lin	48.5 (5.8)	–	–	6.9	0.360	0.188	0.631
Oats	log	0.016 (0.001)	−0.00025 (0.00012)	−0.000024 (0.000012)	6.9	0.629	0.193	0.782
Rye	lin	49.6 (3.7)	1.26 (0.34)	–	5.9	0.215	0.645	0.830
Potatoes:								
— ware	log	0.015 (0.001)	–	–	25.7	0.446	0.744	0.856
— starch	log	0.011 (0.001)	–	–	8.2	0.278	0.381	0.623
Sugar beets	lin	51.7 (8.4)	2.1 (0.8)	–	8.2	0.015	0.457	0.533
Pulse crops	lin	32.9 (6.5)	1.0 (0.6)	0.19 (0.06)	2.9	0.232	0.540	0.511
Rape seed	log	0.011 (0.002)	–	0.000023 (0.000014)	0.8	0.338	0.465	0.632
Flax	–	–	–	–	2.2	0	0	0
Fodder beets	lin	709 (104)	–	–	2.4	0.140	0.460	0.536
Silage maize	log	0.012 (0.002)	–	–	5.7	0.232	0.311	0.573

[1] Estimated standard deviations between parentheses.

Table 3. Basic weather indices of Dutch arable farm products.

Year	Wheat	Barley	Oats	Rye	Potatoes		Sugar beets	Pulse crops	Rape seed	Flax	Fodder beets	Silage maize
					ware	starch						
1948	0.883	0.806	0.780	0.780	1.089	1.085	1.049	0.665	1.055	1.001	1.075	–
1949	1.192	1.266	1.139	1.061	1.019	1.178	1.016	1.277	1.181	1.130	0.974	–
1950	0.885	1.044	0.938	0.899	0.963	1.016	1.009	1.106	0.660	0.951	1.010	–
1951	0.981	0.962	1.089	1.059	0.944	1.025	0.878	1.041	0.866	0.924	0.842	–
1952	1.052	1.015	1.064	1.001	1.072	1.017	1.075	1.089	1.057	1.018	1.005	–
1953	1.014	0.784	1.031	0.927	0.966	0.888	1.057	0.884	0.977	0.924	1.046	–
1954	0.978	0.977	1.072	1.133	0.936	0.936	0.884	0.884	1.148	0.971	0.962	0.950
1955	0.963	1.098	1.100	1.105	1.017	1.013	1.035	1.101	1.052	1.050	1.106	1.170
1956	0.935	1.062	1.002	1.047	0.912	0.798	0.850	0.676	1.027	0.955	0.872	0.904
1957	1.029	1.150	0.990	1.051	1.034	1.008	0.984	1.045	1.020	0.997	1.070	1.075
1958	0.947	1.090	0.989	1.060	1.047	0.857	1.123	0.994	0.784	1.012	1.215	1.185
1959	1.089	1.017	0.762	0.952	0.783	0.917	0.858	1.042	1.141	0.925	0.564	1.116
1960	1.162	1.151	0.992	1.066	0.999	1.061	1.172	1.162	1.051	1.076	1.255	1.026
1961	0.902	1.018	1.004	0.877	0.984	0.998	1.060	1.056	0.968	1.043	1.109	0.971
1962	1.130	1.153	1.091	1.095	1.037	1.087	0.927	1.257	0.957	1.035	0.898	0.810
1963	0.990	1.013	1.033	1.010	0.954	1.009	0.953	0.967	0.958	1.050	0.986	0.874
1964	1.089	1.122	1.092	1.132	1.072	1.129	1.199	1.080	1.073	1.049	1.139	0.978
1965	0.972	0.973	0.944	0.845	0.926	0.760	0.962	0.835	0.973	1.011	0.811	0.895
1966	0.898	0.875	0.917	0.840	1.040	0.992	0.928	0.759	0.971	0.902	0.917	0.976
1967	1.050	1.049	1.020	1.063	1.182	1.123	1.129	1.266	1.078	1.091	1.135	1.125
1968	0.950	0.889	1.021	1.015	1.056	1.095	1.049	0.980	0.999	1.029	1.131	0.963
1969	0.932	0.951	0.927	1.031	1.009	0.975	1.103	1.018	0.737	1.006	1.093	0.961
1970	0.953	0.747	0.860	0.922	1.070	1.086	1.014	0.990	1.063	0.809	1.036	1.085
1971	0.991	0.882	1.047	1.058	1.113	1.135	1.144	1.026	1.149	1.117	1.059	1.044
1972	0.821	0.966	0.936	0.832	1.111	1.107	0.982	0.780	1.089	1.149	1.004	0.842
1973	0.987	0.979	0.962	0.992	1.060	1.095	0.992	0.945	0.956	1.034	0.975	0.935
1974	1.074	0.968	1.073	1.003	1.092	1.171	0.937	1.059	1.166	1.048	0.972	0.952
1975	0.893	0.911	0.971	0.985	0.919	0.969	0.902	0.988	0.926	0.806	0.913	1.132
1976	0.976	0.947	0.852	0.856	0.853	0.801	0.948	0.751	0.989	0.757	0.854	0.767
1977	0.904	0.959	0.922	0.948	0.913	0.990	0.962	1.001	0.963	0.963	0.990	0.999
1978	1.113	1.081	1.133	1.063	0.996	1.119	1.004	1.018	0.849	1.055	1.007	1.084
1979	0.975	0.982	1.041	1.042	0.947	1.107	0.928	1.030	0.908	1.014	0.973	1.062
1980	0.999	0.994	1.032	1.021	0.984	0.903	0.978	0.824	1.217	0.980	0.989	1.032
1981	1.051	0.962	1.065	0.951	1.018	1.028	1.057	1.011	1.133	1.055	1.078	1.182
1982	1.130	1.206	1.120	1.103	1.033	0.856	1.150	1182	1.016	1.022	1.111	1.126
1983	1.029	0.943	0.883	0.936	0.844	0.834	0.876	1.087	0.901	0.856	0.934	1.038
1984	1.116	1.099	0.942	1.011	1.041	1.047	0.977	1.234	0.899	1.182	0.962	0.894
1985	0.922	1.027	1.025	0.967	1.037	1.061	0.923	0.939	0.940	1.088	0.989	0.932
1986	1.094	1.251	1.220	1.112	1.051	0.894	1.108	1.278	1.050	1.051	1.001	1.085
1987	0.921	1.039	1.050	0.933	1.073	1.099	0.973	0.855	0.948	1.080	1.004	0.873
1988	0.947	0.930	0.941	0.935	0.974	1.024	1.005	0.868	0.949	0.983	1.013	1.020
1989	0.959	0.941	0.852	1.064	0.939	1.013	1.071	0.949	1.016	0.849	1.034	1.047

Table 4. Weather indices of aggregate products in Dutch arable farming.[1]

Year	Cereals	Potatoes	Fodder crops	Total excluding fodder crops	Total including fodder crops
1948	0.807	1.088	1.075	0.939	0.947
1949	1.143	1.056	0.974	1.107	1.099
1950	0.931	0.975	1.010	0.959	0.962
1951	1.037	0.962	0.842	0.989	0.980
1952	1.033	1.060	1.005	1.048	1.045
1953	0.955	0.949	1.046	0.958	0.964
1954	1.053	0.936	0.962	0.987	0.985
1955	1.069	1.016	1.106	1.051	1.054
1956	1.007	0.887	0.872	0.932	0.929
1957	1.045	1.028	1.070	1.030	1.032
1958	1.012	1.001	1.215	1.024	1.034
1959	0.964	0.817	0.579	0.909	0.894
1960	1.101	1.014	1.247	1.091	1.098
1961	0.945	0.987	1.103	0.983	0.988
1962	1.120	1.051	0.893	1.071	1.064
1963	1.008	0.968	0.977	0.988	0.988
1964	1.103	1.086	1.121	1.112	1.112
1965	0.948	0.885	0.824	0.931	0.928
1966	0.888	1.027	0.929	0.938	0.937
1967	1.046	1.167	1.133	1.109	1.110
1968	0.956	1.066	1.084	1.017	1.019
1969	0.948	0.999	1.043	1.001	1.002
1970	0.886	1.074	1.065	0.991	0.993
1971	0.979	1.119	1.050	1.078	1.076
1972	0.872	1.110	0.871	1.001	0.995
1973	0.983	1.070	0.942	1.021	1.016
1974	1.041	1.110	0.956	1.051	1.043
1975	0.912	0.930	1.126	0.919	0.939
1976	0.949	0.842	0.772	0.894	0.880
1977	0.922	0.930	1.001	0.937	0.944
1978	1.105	1.023	1.085	1.037	1.043
1979	0.985	0.989	1.064	0.971	0.983
1980	1.001	0.962	1.035	0.978	0.985
1981	1.033	1.020	1.184	1.035	1.056
1982	1.142	0.995	1.129	1.073	1.081
1983	1.004	0.842	1.039	0.895	0.917
1984	1.103	1.042	0.898	1.044	1.020
1985	0.946	1.043	0.936	0.985	0.977
1986	1.131	1.013	1.084	1.076	1.077
1987	0.951	1.079	0.875	1.010	0.988
1988	0.943	0.985	1.020	0.977	0.984
1989	0.953	0.955	1.046	0.988	0.998
Average				1.003	1.004

[1] Annual value shares and centered value shares are available on request from the author.

Table 5. Normalized production in kg per hectare of arable farm products.

Year	Wheat	Barley	Oats	Rye	Potatoes		Sugar	Pulse crops	Rape seed	Flax	Fodder beets	Silage maize
					ware	starch						
1948	3659	3112	2857	2667	23783	25614v	6912	2195	1990	7847	59459	–
1949	3698	3160	2870	2667	24145	25902	6881	2364	2057	7847	60168	–
1950	3739	3209	2889	2668	24513	26192	6854	2513	2119	7847	60877	–
1951	3783	3257	2915	2673	24886	26486	6831	2643	2178	7847	61586	–
1952	3828	3306	2946	2680	25265	26784	6812	2756	2233	7847	62295	–
1953	3875	3354	2983	2689	25650	27084	6797	2852	2284	7847	63004	–
1954	3925	3403	3026	2701	26041	27388	6786	2932	2331	7847	63713	8505
1955	3977	3451	3075	2715	26438	27696	6780	2998	2374	7847	64422	8606
1956	4032	3500	3128	2732	26841	28006	6778	3051	2413	7847	65131	8710
1957	4089	3548	3187	2751	27249	28321	6779	3092	2449	7847	65839	8814
1958	4149	3597	3250	2773	27665	28639	6785	3122	2481	7847	66548	8919
1959	4211	3645	3318	2798	28086	28960	6795	3141	2510	7847	67257	9026
1960	4276	3694	3390	2825	28514	29285	6810	3153	2536	7847	67966	9134
1961	4344	3742	3466	2854	28948	29614	6828	3156	2559	7847	68675	9244
1962	4415	3791	3546	2886	29389	29946	6851	3153	2580	7847	69384	9354
1963	4489	3839	3629	2920	29837	30383	6878	3145	2598	7847	70093	9466
1964	4567	3888	3716	2957	30292	30622	6908	3133	2614	7847	70802	9580
1965	4647	3936	3804	2997	30753	30966	6944	3117	2629	7847	71511	9694
1966	4731	3985	3895	3039	31222	31314	6983	3100	2643	7847	72220	9810
1967	4819	4033	3987	3083	31697	31665	7026	3081	2656	7847	72929	9928
1968	4910	4082	4081	3130	32180	32020	7074	3063	2668	7847	73638	10047
1969	5005	4130	4174	3180	32670	32380	7125	3047	2680	7847	74347	10167
1970	5104	4179	4267	3232	33168	32743	7181	3033	2693	7847	75056	10289
1971	5207	4227	4360	3287	33673	33111	7241	3022	2706	7847	75765	10412
1972	5315	4276	4450	3344	34186	33482	7305	3017	2720	7847	76474	10536
1973	5427	4324	4538	3403	34707	33858	7374	3017	2735	7847	77183	10663
1974	5544	4373	4622	3466	35236	34238	7446	3024	2753	7847	77892	10790
1975	5666	4421	4701	3530	35773	34623	7523	3039	2772	7847	78601	10919
1976	5793	4470	4775	3597	36318	35011	7604	3064	2795	7847	79309	11050
1977	5925	4518	4843	3667	36871	35404	7689	3099	2820	7847	80018	11182
1978	6063	4567	4903	3739	37433	35801v	7778	3146	2849	7847	80727	11316
1979	6206	4615	4955	3814	38003	36203	7871	3205	2882	7847	81436	11452
1980	6356	4664	4997	3891	38582	36610	7968	3278	2920	7847	82145	11589
1981	6513	4712	5028	3971	39170	37021	8070	3366	2963	7847	82854	11728
1982	6676	4761	5049	4053	39766	37436	8176	3470	3013	7847	83563	11868
1983	6846	4809	5057	4138	40372	37856	8285	3592	3068	7847	84272	12010
1984	7023	4858	5052	4225	40987	38281	8399	3731	3132	7847	84981	12154
1985	7208	4906	5033	4315	41612	38711	8518	3890	3203	7847	85690	12300
1986	7401	4955	5000	4408	42246	39145	8640	4069	3284	7847	86399	12447
1987	7602	5003	4952	4502	42889	39585	8766	4270	3375	7847	87108	12596
1988	7812	5052	4890	4600	43543	40029	8897	4494	3477	7847	87817	12747
1989	8032	5100	4812	4700	44206	40478	9032	4742	3593	7847	88526	12899
Average growth (% $year^{-1}$)	1.94	1.21	1.28	1.39	1.52	1.12	0.65	1.90	1.45	0	0.98	1.20

The normalized production levels are in Table 5. Most products show a positive trend in the normalized production per hectare. Flax is an exception: no significant trend could be detected, and a constant normal yield level was the result. This can be due to the large changes in area with different potential yields. There are remarkable differences in systematic yield developments between the different products. Figure 1 gives an overview of the weighted annual increase of these yields. Here we observe first a slightly declining and later on an increasing development in the growth of yields. Average annual yields increased by 1.17 and 1.48 % over the periods 1949-1969 and 1969-1988, respectively. The figure illustrates the continuous, development in yields during a longer period. Annual increases are now at a level of nearly 1.7 %.

Comparing systematic yield developments in the Netherlands and the UK, annual increases are about 30 % lower in the Netherlands (Britton, 1990, p. 5). Annual increases of wheat yield in the Netherlands are about 20% lower than that of the 'Total world excluding China' (Anderson & Hazell, 1989, p. 24). This illustrates that long-term growth rates are relatively low in the Netherlands. A number of related measures has been presented in Tables 6 and 7.

Table 6 gives correlations between all weather indices of individual products and the aggregated index. They illustrate that all products have a positive correlation with the aggregate weather index. The correlation for ware potatoes and sugar beets are highest, also due to the large share of these products in total arable production. A principal component analysis on 11 'individual' weather indices indicated that the

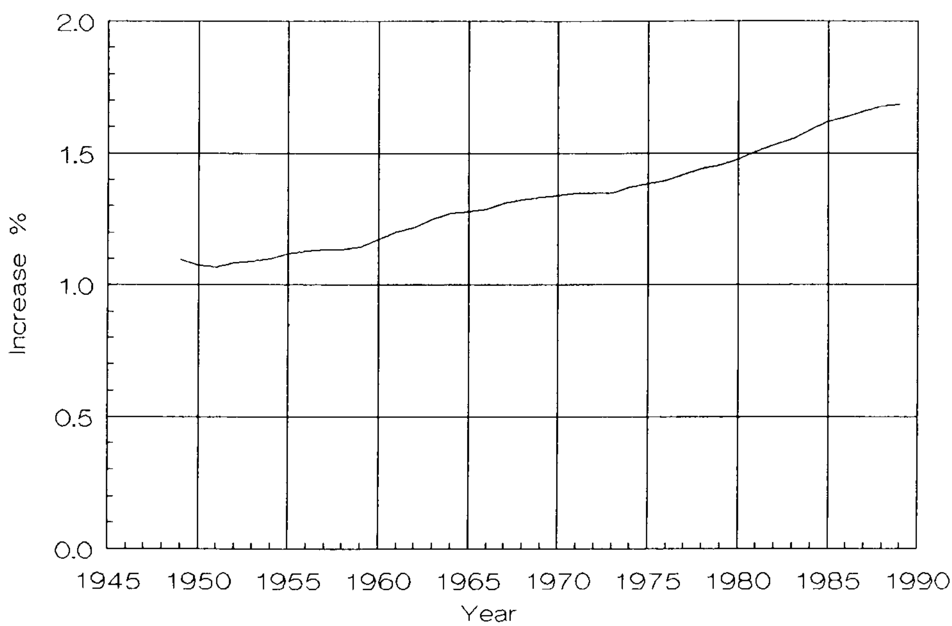

Fig. 1. Weighted annual yield increase of arable crops (1949-1989); systematic increase.

first principal component represented 40 % of the total variance, the first three principal components took 70 % and the first five components 85 %. This implies that weather cannot be represented by one particular factor alone (a linear combination of individual weather indices) or by one representative crop. The value share of a particular product is, of course, an important indicator to incorporate a specific weather index. However, for similar products (like potatoes or cereals) the main product alone may be sufficient in calculating an aggregated weather index.

Table 6. Correlation between weather indices of particular crops and the weather index of arable products.

Product	Correlation
Wheat	0.55
Barley	0.44
Oats	0.71
Rye	0.65
Ware potatoes	0.74
Starch potatoes	0.38
Sugar beets	0.73
Pulse crops	0.55
Rape seed	0.31
Flax	0.64
Fodder beets	0.72
Silage maize[1]	0.32

[1] Period 1954-1989.

Table 7. Standard deviations of weather indices during two different subperiods.

Product	Period	
	1948-1968	1969-1989
Wheat	0.090	0.083
Barley	0.119	0.107
Oats	0.096	0.100
Rye	0.103	0.074
Ware potatoes	0.082	0.078
Starch potatoes	0.108	0.106
Sugar beets	0.101	0.078
Pulse crops	0.175	0.135
Rape seed	0.119	0.116
Flax	0.061	0.117
Fodder beets	0.156	0.059
Silage maize	0.101[1]	0.107
Total excluding fodder crops	0.065	0.055
Total including fodder crops	0.066	0.053

[1] Period 1954-1968.

Discussion

As expected, weather indices for individual crops vary more than weather indices for the total arable sector (see Table 7). Only with a perfect positive correlation between the weather indices for the individual products, would the resulting index be a weighted average of individual indices. The most extreme observed difference in indices is about 23 % of a normal harvest (between the years 1964 and 1976) as can be observed in Table 4. Furthermore, calculations over the period 1948-1989 indicate that 30 % of the total variance of 'weighted yields' was due to weather variation and 70 % to systematic variation. Increasing the period implies that the share of weather variation is declining. The systematic developments in yield accounted for 33 and 53 % of total variation in 1948-1968 and 1969-1989, respectively. This difference is partly due to the smaller increase of yields in the first period (see Figure 1). For an average year the systematic development is about 1.3 % of a normal yield, while the weather variation is nearly 6 %; a good illustration that weather variation is important in short-term periods.

A second point of investigation is the variation, due to changing weather in the first and the second half of the total period. First of all we tested if the weather index was significantly different from a normal variable with expectation 1. With a 5 % level of significance we could not reject the hypothesis that the weather index had a normal distribution. Using a Komolgorov-Smirnov test, no difference could be found between the weather index and a normal variable. All individual crops showed no significant differences with the normal distribution, even at the 20 % significance level. Some crops had a slight positive skewness, others a small (but insignificant) negative.

The standard deviation of yield, in relation to 'normal' yields is represented by the standard deviations of the weather indices. They have been shown in Table 7. Relative yield variability is mostly lower in the second part of the period, although there are differences between crops, while at an aggregate level yield variability is reduced by 15-20 %. Yield levels, however, increase by more than 20 % in the second part of the period compared with the first part.

Comparisons of our results with the work of Stallings (1960, 1961) show that variation due to weather conditions is much smaller in the Netherlands than in the United States. Other research sources on yield variation confirm this conclusion (Anderson & Hazell, 1989; Weber & Sievers, 1985). However, relative yield variations of cereals in the Netherlands are comparable to variations in countries such as France, Germany and the UK.

Critical remarks

A number of remarks can be made about the methodology applied. Most important is that all stochastic factors influencing the yields of arable products are considered as weather effects; also diseases and plagues are contained in the weather indices. This implies that non-smooth changes in economic conditions (e.g. price changes of products or inputs influencing the optimum yield level) are also incorporated in the weather effects. The effects of these biases are unimportant, however, when yield levels show large variation due to weather conditions and small variations due to price variation. Due to relative small variation of expected prices and also small variation of the optimum yield levels (de Wit, 1988), these biases seem to be unimportant.

Another point is that some variation in production will now show up in yield levels. Also the area of a particular crop can be influenced by weather conditions. To give an example, a part of the winter wheat can be substituted by spring barley when the winter weather is severe. This may pass unobserved because both winter wheat and spring barley may show normal yield levels. We assume, however, that in the Netherlands differences between planned and actual areas for the particular crops are small due to limited weather variation in winter and spring.

Systematic yield levels can be influenced by technical developments as well as by important changes in the area of products. Important shifts in the area of product can have a large influence on the average expected yield. Especially green maize, cole seed, flax, fodder beets, oats and rye show important area shifts.

Concluding marks

Although the calculated weather indices and the related normalized yields have a number of drawbacks, they form the only consistent long-term source in this area. Therefore, these numbers could be useful for several types of economic research. The numbers for individual products can also be useful for technical research. They give a comprehensive overview over a longer period.

Here we have calculated numbers for the Netherlands. The same methodology can be used for regional data. Weather indices for individual crops could be used for the calculation of weather indices at an individual farm level. Such an index depends on the composition of crops produced. It might be, however, that regional differences between farms are also important.

References

Amemiya, T., 1980. Selection of regressors. *International Economic Review* 21: 321-354.

Anderson, J. R. & P. B. R. Hazell (Eds), 1989. Variability in grain yields. The Johns Hopkins University Press, Baltimore, 395 pp.

Britton, D. (Ed.), 1990. Agriculture in Britain: changing pressures and policies. Commonwealth Agricultural Bureau International, Wallingford, 215 pp.

Chambers, R. G., 1988. Applied production analysis; A dual approach. Cambridge University Press, Cambridge, 331 pp.

Cromarty, W. A., 1959. An econometric model for United States Agriculture. *Journal of the American Statistical Association* XXX: 556-574.

Doll, J. P., 1967. An analytical technique for estimating weather indices from meteorological measurements. *Journal of Farm Economics* 49: 79-88.

Judge, G. C., W. E. Griffiths, R. C. Hill & T-C. Lee, 1980. The theory and practice of econometrics. Wiley, New York, 810 pp.

Murdoch, D. C., 1966. Linear Algebra for Undergraduates. Wiley, New York, 239 pp.

Oskam, A. J., 1987. WASmodel. (In Dutch). Wageningse Economische Studies 1, Wageningen Agricultural University, Wageningen, 74 pp.
Oskam, A. J., 1991. Productivity measurement, incorporating environmental effects of agricultural production. In: K. Burger et al. (Eds), Agricultural economics and policy: international challenges for the nineties, p. 186-204. Elsevier, Amsterdam.
Oskam, A. J. & A. J. Reinhard, 1992. Weather indices for agricultural production in the Netherlands 1948-1989. 2. Grassland and total agriculture. *Netherlands Journal of Agricultural Science* 40 (in press).
Oskam, A., A. Reinhard & G. Thijssen, 1989. WASmodel-2: A disaggregated agricultural sector model partly based on prior information. In: S. Bauer & W. Henrichsmeyer (Eds). Agricultural Sector Modelling, p. 53-69. Wissenschaftsverlag Vauk, Kiel.
Oury, B., 1965. Allowing for weather in crop production model building. *Journal of Farm Economics* 47: 250-282.
Oury, B., 1966. A production model for wheat and feedgrains in France. North-Holland Publishing Company, Amsterdam, 306 pp.
Shaw, L. H., 1964. The effect of weather on agricultural output: a look at methodology. *Journal of Farm Economics* 46: 218-230.
Stallings, J. L., 1960. Weather indices. *Journal of Farm Economics* 42: 180-186.
Stallings, J. L., 1961. A measure of the effect of weather on crop production. *Journal of Farm Economics* 43: 1153-1160.
Thijssen, G. J., 1989. Production theory and dairy farms. (In Dutch). Wageningse Economische Studies 14. Wageningen Agricultural University, Wageningen, 95 pp.
Velde, H. A. te, 1984. Constraints on maize production in northern latitudes. In: E. J. Gallagher (Ed.), Cereal Production, p. 325-341. Butterworth, London.
Weber, A. & M. Sievers, 1985. Instability in world food production: statistical analysis, graphical presentation and interpretation. Wissenschaftverlag Vauk, Kiel, 154 pp.
Wit, C. T. de, 1988. Environmental impact of the CAP. *European Review of Agricultural Economics* 15: 283-296.