Thermal characteristics of different types of soil

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1. Introduction

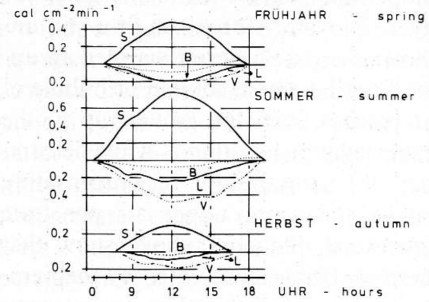
It is desirable for glider pilots planning cross-country flight to know which areas and types of terrain and soil are more advantageous in producing thermal convection than others. Methods will be presented for getting a better understanding in qualification and—up to a certain degree—quantification of those different types of terrain. Methods based on measurements of vertical velocity are called direct, the other ones indirect..

2. Direct Method—Measurement of Vertical Velocity

Figure 1 has already been presented in a former paper (Lindemann, 1978). It shows the results of 17 flights in a height of about 150 m above ground performed during a measurement campaign in May 1976. The percentage of meeting a thermal is shown. Even under cold air advection it is very small above a lake, which is still very cold in May, and it is high, up to 60%, above a hill facing the sun. An area with small lakes and relatively wet soil has a very low percentage of producing a thermal compared with a partly sandy moor. The relation between both is about one to three. These percentage relations can be expected to be valid for a longer period of time than the measurement campaign. The relations within each individual flight show similar behavior.

A very high correlation was found between the average maximum vertical velocity and the average maximum temperature excess for those flights indicating the relations to vertical heat flux in a particular height. Additionally this means that frequency of occurence of thermals and magnitude of vertical velocity are proportional. Taking into account measurement flights of a total length of about 2000 km, a sufficient correlation exists between the average maximum values of vertical velocity and temperature excess at 700 m AGL, which is much better for all areas than the above mentioned.

So we used the average maximum vertical velocity to qualify the sandy region near Oerlinghausen, Germany, an arable soil region south of that sandy region which reaches Paderborn, and an arable soil region north of Oerlinghausen. An average maximum vertical velocity (36 flights) of 4.3 m/s was found for the Oerlinghausen area, of 3.0 m/s for the southern region, and of 2.7 m/s for the northern region. The maximum value of vertical velocity of all three areas was not always found in the Oerlinghausen area, sometimes it occurred in the second area, but never in the last one, which clearly could be identified as the thermally weakest of those three neighbouring areas.



S = radiation balance
B = heat flux into the ground
V = evapotranspiration
L = sensible heat flux

Fig. 2 Daily energy balance during clear days only with small winds at Quickborn (after Frankenberger).
Täglicher Wärmeumsatz an klaren, windschwachen Tagen zu Quickborn in Holstein (nach Frankenberger).

3. Indirect Method: Qualification of Soil

Characteristics of soil allowing conclu-

Thermische Eigenschaften verschiedener Boden- und Vegetationstypen

Es ist wünschenswert und notwendig, dass Segelflieger bei der Planung von Überlandflügen wissen, welche Gebiete sich hinsichtlich Bodenart, Bedeckung, Bewuchs, orographischer Struktur usw. für die Entwicklung von thermischer Konvektion eignen und welche nicht. In den folgenden Ausführungen werden 2 Methoden beschrieben, die eine bessere qualitative Abschätzung ermöglichen und bis zu einem gewissen Grad auch eine quantitative Beurteilung verschiedener Bodentypen erlauben. Es ist dies einmal die direkte Methode über die Messung der Vertikalgeschwindigkeit des Segelflugzeuges; zum andern erfolgt eine indirekte Betrachtung der physikalischen Eigenschaften des Bodens und der Vegetation unter Anwendung der Energiebilanzgleichung am Erdboden.

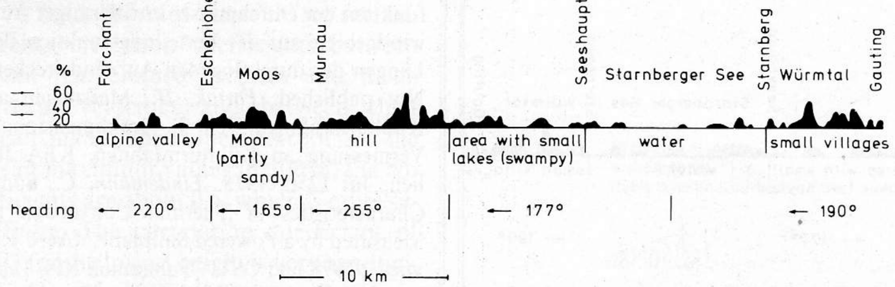
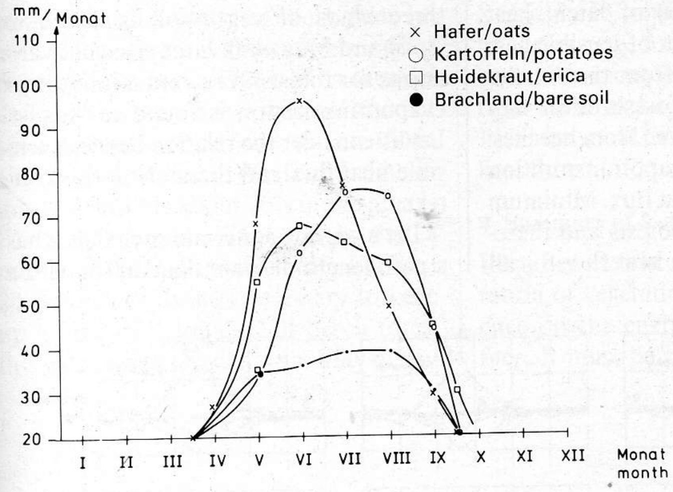


Fig. 1 Percentage of probability of meeting a thermal. Results of 17 flights from Gauting to Farchant from 5th to 11th of May, 1976.



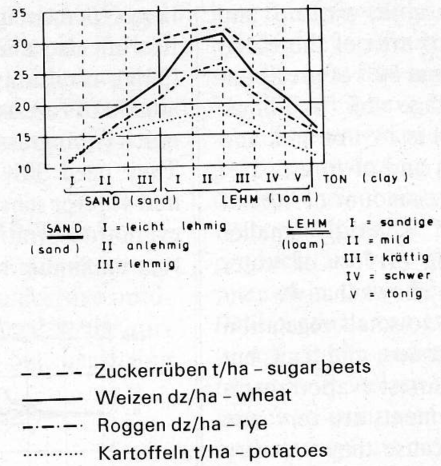


Fig. 3 Evapotranspiration of oats, potatoes, bare soil and erica. Evapotranspiration von Hafer, Kartoffeln, Brachland und Heidekraut (nach/after Lützke [1961–1965], Eberswalde).

Fig. 4 Crop of different types of soil (after Sagawe). Ertragsleistung verschiedener Bodenarten (nach Angaben von Sagawe).

sions of thermal strength have often been mentioned in the literature and are well known among advanced glider pilots. A first thermal map was published by Kottmeier et al. (1980), who evaluated the experience of pilots during their cross-country flights in combination with soil characteristics. Soil types can be distinguished as sandy, loamy, and clayish depending on granulation or resulting from of biological forces. Then we call it podsol, brown earth, or fen for example. But first we have to look for the physical principles determining the vertical flux of sensible heat, which is the source for thermal convection. The energy balance equation for the surface is:

$$S = B + L + V,$$

where
S: radiation balance at the ground,
B: heat flux into the soil,
L: sensible heat flux from the surface to the atmosphere, and
V: latent heat flux, which is proportional to evapotranspiration. L is that part of this balance equation, which is finally responsible for thermal convection energy.

Figure 2 shows an example of measurements of all terms of this balance equation for clear days with light winds over grass at Quickborn, Northern Germany (after Frankenberger, 1955). Latent heat flux is the dominant term in summer and autumn, whereas heat flux into the ground and sensible heat flux into the atmosphere are of secondary order.

Thus it is necessary to know the factors determining latent heat flux. Figure 3 shows measurements of average evapotranspiration of oats, potatoes, erica, and bare soil, all on sandy ground at Eberswalde near Berlin (Lützke, 1969a). There it is pointed out that the soil itself probably has a minor influence on latent flux compared with vegetation. The evapotranspirationrates of bare soil and oats differ up to a factor of three. Additionally it clearly depends on the season. Oats, as many other grains, have a maximum evapotranspiration in June and July during earing, while potatoes and sugar beets have their maximum water consumption in July and August. Sandy ground is best represented here by bare soil, but knowing that more than 90% of Central Europe is covered by vegetation, investigations about latent heat fluxes must include vegetation characteristics.

Blaney and Criddle (1970) have developed a relation which gives the monthly water consumption for different field products as a function of their growth period, when optimal crop is expected. It can be computed from mean monthly temperature and mean monthly daylight hours for any place, but it turned out to give too large values for areas outside arid climates. Other methods for computing water consumption or potential evapotranspiration have been developed by Penman, Haude, Thornthwaite (see Schendel, 1967) and others, who partly consider water vapour gradient and wind additionally. The following growth rate factors from Blaney and Criddle (1970) are cited here to show the relations between different kinds of vegetation in spite of their water consumption and thus their evapotranspiration: Grains from 1.0 to 1.1, potatoes 1.15, sugar beets 1.25, and pasture grass 1.35.

As the availability of water for vegetation is dependent on the type of soil, and thus of its water table, relative figures only count for the same type. Figure 4 shows the different kinds of vegetation growing on different types of soil and the corresponding height of the crops. It follows that maximum crop can be found in loamy earth for all types mentioned. Sugar beets have only a small range of fertility, while rye and potatoes can be planted into all kinds of those soils although minor crop can be expected for more sandy and more clayish soil. Besides relations in very clayish soil, literature (Klapp, 1967, Becker, 1961, among others) tries to prove a fruit specific constant relation between dry content of fruit and water consumption.

It is important to look for seasonal vegetation, even if it covers only 30% of the total area of the Federal Republic of Germany for example. After Bechtel (1971) these seasonal vegetations evapotranspirate about 45% of the total precipitation per year, while pasture and other grasses (27% of area of the FRG) evapotranspirate about 60% of precipitation. The percentage of buildings, streets, and bare soil is 13% of area and 30% of precipitation and of forests 28% of area and the large amount of 70% of precipitation, which is hardly smaller than the evaporation of 75% of water surfaces. This survey shows that we cannot restrict ourselves to small vegetation such as root crops, grains, and fruit, but we have to consider forest evapotranspiration, too. Measurements are very rare in the literature, because they are very expensive.

Tajchmann (1967) compares the terms of the energy balance equation for alfalfa, potatoes, and spruce forest in Bavaria, all on similar types of soil (Figure 5). There spruce forest has the largest flux of sensible heat for all times presented, and alfalfa, which is known as very water-consumptive, the smallest. Potatoes, shown here during the period of their highest consumption, evapotranspirate nearly as much as spruce forest, but have a lower flux of sensible heat, because of their larger albedo. This can be seen from the lower radiation balance.

Lützke (1969b) found that a pine forest of an age of 28 years evapotranspirates much more than pasture grass and additionally has a larger flux of sensible heat, resulting from its smaller albedo.

Further direct measurements comparing different types of vegetation at the same time and site are not known to the author. So we try to make a comparison between measurements, which are made at different times, different synoptic situations and at different places.

Berz (1969) made long-time measurements of the terms of the energy balance equation in pasture grass, Kiese (1972) investigated a beech forest, and Schott (1980) made measurements in a pine forest. We will now try to generalize the above results.

The percentage of sensible and latent heat in the radiation balance is computed for the daylight hours between 8 and 17 hours (MEZ). Figure 6 shows results of the comparison: Grass has a latent heat flux of about 60% averaged for April until September and a sensible heat flux of only 21%. Beeches have a larger percentage (62%) of latent heat flux but also a larger flux of sensible heat (29%), resulting again from the smaller albedo of forests. Pine forests differ very much from grass and even from beeches: They need 50% for evapotranspiration and 41% for sensible heat flux. Minimum evapotranspiration of forests and therefore maximum sensible heat flux for all three kinds of vegetation is found in April and May, with large seasonal variations for forests. A second minimum of evapotranspiration is found in August. Let us consider the relation between sensible heat flux and thermals in this context.

Let us define a thermal such that it has a path length of more than 100 m with a

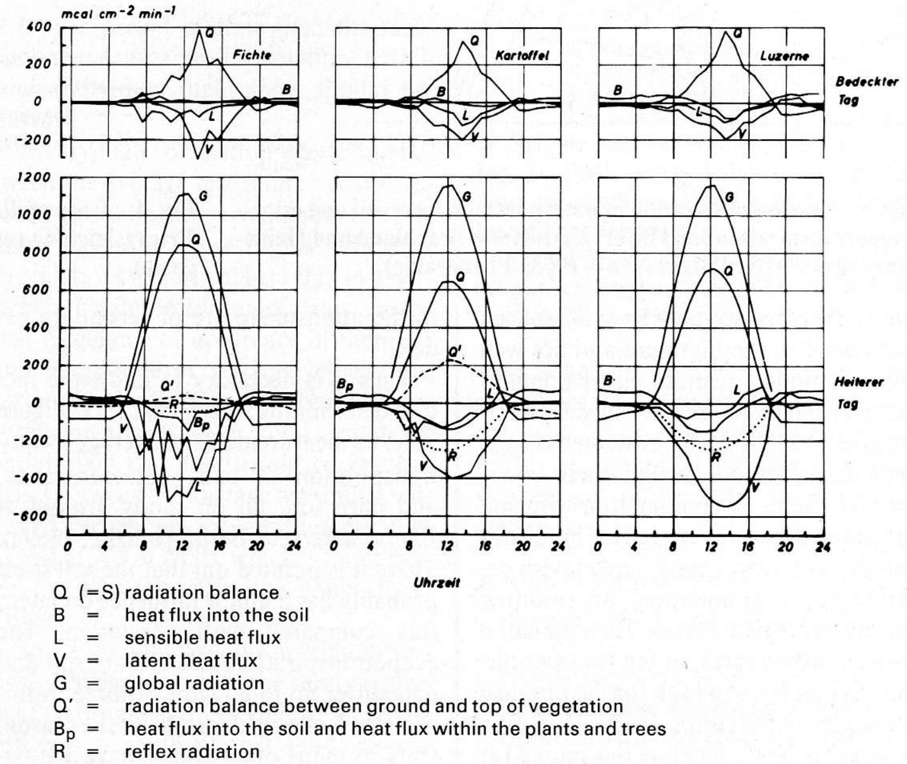


Fig. 5 (Tajchmann) Energy balance of spruce (Fichte), potatoe (Kartoffel), and alfalfa (Luzerne) for a covered and a clear day near Munich.

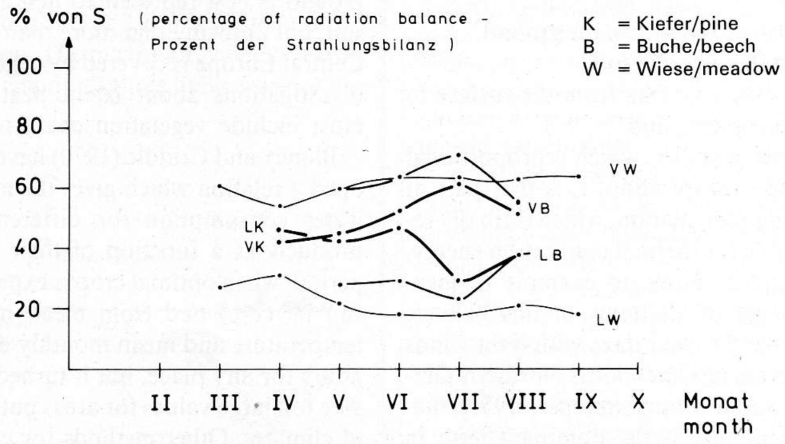


Fig. 6 Fluxes of sensible (L) and latent (V) heat as percentage of radiation balance. Prozentualer Anteil der Ströme fühlbarer und latenter Wärme in der Strahlungsbilanz (nach/after Schott, Kiese, Berz).

mean vertical velocity of more than 1.5 m/s. The author has shown in an earlier paper (Lindemann, 1978) that a thermal defined this way has a vertical flux of sensible heat of 1 cal/cm²/min at 100 m above ground level. We found that in this low altitude about 20% of the area is filled by thermals. That means that a minimum flux of sensible heat of at least 200 mcal/cm²/min is necessary to keep up a field of thermals. For beech forest this value was exceeded from May to August only 13 times at 12.00 h MEZ and for grass only 5 times. The pine forest, however, exceeded the threshold value from April to August between 11.00 and 14.00 hours MEZ in the monthly mean heat flux.

4. Summary of Vegetation Studies

It has been worked out that evapotranspiration of vegetation has a decisive influence on the energy balance at the surface. It must be pointed out, neglecting heat flux into the ground for a moment, that high evapotranspiration means low sensible heat flux and thus less thermals. These results have been collected from very different sciences such as hydrology, forest hydrology, agronomy, and, of course, meteorology. The relations of evapotranspiration of different field products are very clear, when they are planted in the same type of soil. Many field products can grow in a large range of soil quality and it happens that vegetation with relatively low water consumption compared to other kinds, will evapotranspirate more on wet soil than a field product with high water consumption on dry soil. But we have seen that some species have a very small range of usable soil. So we have to keep in mind that for most kinds of vegetation a wide range of possible evapotranspiration rates exists. But on the other hand farmers are interested in getting big crop, so, whenever possible, they will plant field products which are most efficient on the farmland available. There exists a relationship in literature (Klapp, 1967) between the percentage of available farming land of a special soil type and the different field products planted on it. There it follows that grassland occupies mostly clayish and wet soil type, whereas sugar beets, which are highly water-consumptive, are seldom found on sandy soil and podsols. Sandy podsols are covered by vegetation only by 75%, whereas 25% are bare soil.

Figure 7 represents a compilation of all results collected from Becker (1961), Berz (1969), Brechtel (1971), Blaney and Criddle (1970), Klapp (1967), Kiese (1972), Lützke (1969a, b), Schott (1980), and Tajchmann (1967), for Central European conditions for the period from April to August. The vertical axis shows the evapotranspiration in mm/month. The figures exhibit the range of a single species. The area corresponding to each species is subdivided into clayish, loamy and sandy, and is proportional to the area coverage. Bare soil, as already mentioned, is mostly found on sandy podsols, potatoes have a wide range of possible types of soil, while sugar beets with high evapotranspiration are mostly found in loamy soil. Forests have a very wide range of evapotranspiration. Clear-

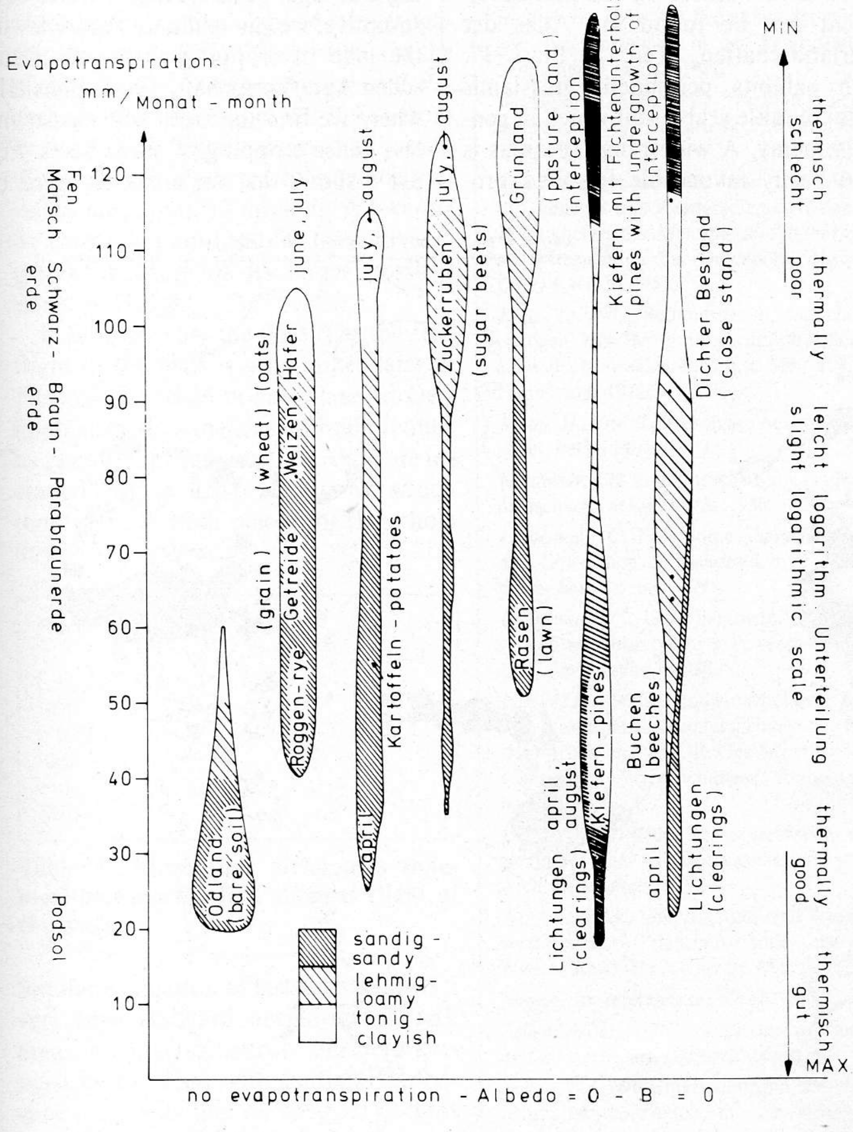


Fig. 7 Monthly evapotranspiration of different kinds of vegetation as a function of type of soil. Classification in loamy, clayish, and sandy corresponds to the relative land utilization of the single kind of vegetation. Evapotranspiration is approx inverted proportional to flux of sensible heat (construction after Becker, Blaney—Cridde, Klapp, Kiese).

ings in forests have a very low evapotranspiration and are even better for producing thermals than bare sandy podsols because of their smaller albedo. The denser a forest, the larger the evapotranspiration.

A very high amount of evapotranspiration of forests is due to evaporation of intercepted rain, which is caught by the tree tops and therefore without interfering with the ground. High seasonal water consumption of vegetation species is shown at the top of the figure, low consumptions at the bottom. Near the vertical axis some typical soil types are named, which cover the surface of Northern Germany.

5. Construction of a Thermal Map

Regarding Figure 6 we see for most vegetation species a wide range of thermal qualities. So we have to restrict our considerations to those species, which exhibit a small range. On the left side we see that podsols have a very large percentage of bare soils which consume only little water. So we expect them to be highly efficient at producing thermals. On the other side we see that sugar beets and grassland have a small range only at the thermally poor side.

Loamy soil is usable for all kinds of field products with high crops. Clayish soil is mostly covered by permanent grassland and fruits. Podsols—with a high percentage of bare soils—are depicted in Hollstein (1963).

Soils unfavourable for thermal development can be found in "Atlas der Agrarlandschaften, Teil I, Blatt I", which exhibits permanent grasslands and favourable arable soil which in general is loamy. A wide range of areas is called partly favourable for field products, which means that the soil is not so efficient because of different reasons, which can be a water table too low for demanding field products such as sugar beets and oats. Aiming at a better qualification for that white area (Figure 7) one must get to know the kind of vegetation growing there and its density. Knowing that farmers are forced to practice rotation of crops, we cannot expect a map to be valid for all times.

Figure 8 is the summary of thermally good areas - podsols - and of thermally poor areas - permanent grassland and soil most favourable for farming. Knowing that sugar beets are highly water-consumptive, we can compare Figure 8 with the map of cropping (Atlas der Deutschen Agrarlandschaft, Teil I, Blatt III), where we find the areas with dense and less dense cropping of sugar beets. Figure 9 shows that the areas occupied by

Fig. 8 Qualification of soil for development of thermal convection.
Die Qualifikation des Bodens für die Erzeugung thermischer Konvektion.

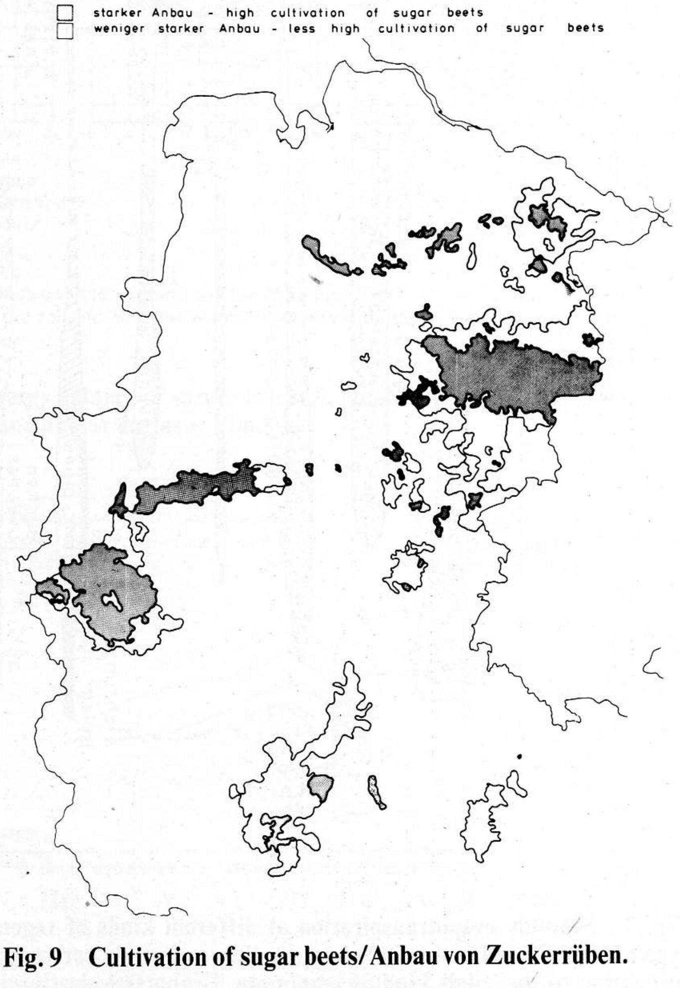


Fig. 9 Cultivation of sugar beets/Anbau von Zuckerrüben.

sugar beets fit very well with the most favourable cropping areas (and thus less favourable for thermals) of Figure 8. We keep in mind that these arguments are rather qualitative than quantitative.

6. Evaluation of Flight Logs from Different Gliding Fields

It is known qualitatively that the first thermal flight of the day in a thermally good area is earlier than in a thermally poorer area. The last thermal flight in the former is later, the thermals are stronger and often more frequent.

So it is interesting to know whether such data can be derived from standard flight logs of active clubs. An investigation was made for 1979 and 1980 for the gliding fields at Oerlinghausen and Paderborn (see below) about 30 km from each other. A flight is defined a thermal flight when it is started by a winch and lasted more than 12 minutes. A take-off by aerotow is not used for these investigations because of its larger possible range and height.

It follows from the data that the first flight in thermals is 40 minutes later at Paderborn and 16 minutes later at Oerlinghausen than the ideal of both. It must be mentioned that only those days are included, where active flying by winch took place at both places for the whole day.

Place	Paderborn	Oerlinghausen	Number of days
1. flight 1979	44	19	42
1. flight 1980	37	12	37
sum 79/80	40	16	79

Table 1 Mean time differences (minutes) between the first thermal flight of two places.

Similar evaluation of last flights shows a very high standard deviation for both areas, so that statistical considerations must be regarded with caution. Experience often tells that on some days clubs stop flying before thermals have disappeared completely. Comparing all data of both areas—only the days when all clubs under consideration were active—there is an advantage for Oerlinghausen. The average time difference between Oerlinghausen and Paderborn for the first thermal flight of a day is about half an hour. To the present state of knowledge it can be assumed that cold air advection reduces time differences.

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