Estimating aerial biomass in semi-natural vegetation from spectral reflectance measurements. 1. Preliminary experiences

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ESTIMATING AERIAL BIOMASS IN SEMI-NATURAL VEGETATION FROM SPECTRAL REFLECTANCE MEASUREMENTS 1. PRELIMINARY EXPERIENCES

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SUMMARY

A technique of calculating aerial green biomass from spectral measurements in the red and near infrared bands is increasingly being applied in vegetation studies. It is fast, non-destructive and can be directly applied from aircraft or satellite mounted sensors to large areas. Literature data illustrating the potential of the approach refer sofar generally to rather ideal situations in low, open, herbaceous vegetation.

Before general application can be recommended a body of reference including various situations should be available. The present contribution indicates some disturbing factors such as the presence of flowers or shade and evaluates the applicability of the technique for a number of vegetation types. Results of tests in 11 semi-natural vegetation types are presented, ranging in height from 30–150 cm and in cover from 20–100%. Measurements were made with – as later appeared – non-optimal equipment and no correction could be made for variation in incoming radiation. Multiple sampling at three to five dates between April and July resulted in correlation coefficient values of 0.96, 0.95, 0.92, 0.91, 0.91, 0.88, 0.85, 0.82, 0.67, and -0.06 (in the last case *Holcus lanatus* dominant) for aerial biomass dry and the $\frac{IR}{R}$ ratio. These relatively high values are critically examined. The data provide evidence for a rather general applicability of the technique, but also for a cautios approach and a mandatory calibration per (floristically and/or physiognomically) different vegetation type.

1. INTRODUCTION

Estimates of the amount of above-ground vegetation, referred to as aerial biomass or standing crop, are used in many kinds of vegetation studies. Where the vegetation is studied as an exploitable renewable natural resource in itself, estimates of the amount of harvestable plant material are essential. Grazing potential research and the evaluation of rangelands are obvious examples (STODDART et al. 1975). Traditionally clipping and weighing of vegetation in sets of sample plots has provided the estimates. The method is time consuming and, where manpower is expensive, costly (BROWN 1954). It is destructive as well, preventing repeated measurement of the same sample plots to estimate vegetation productivity.

Non-destructive techniques of estimating standing crop have been devised, such as measuring attributes (cover, height, volume) directly related to the amount of vegetation. Standing crop is then calculated from measurements or ocular estimates of these parameters and already established regression equations, often by means of a double sampling technique (PECHANEC & PICKFORD 1937; BROWN 1954; KINSINGER & STRICKLER 1961; MASON & HUTCHINGS 1967; THALEN 1979).

Of the equipment developed for non-destructive measurement, the use of electronic capacitance instruments is best known, not only in herbaceous but also in shrub vegetation. The technique has disadvantages and is not suitable for determination of aerial biomass over large areas (NEAL & NEAL 1973; CURRIE et al. 1973; MORRIS et al. 1976).

An approach of using spectral reflectance measurements in selected narrow wavelength bands has been developed in the last decade and is now widely being tested. Such measurements are rapid, non-destructive and can be made from different altitudes, related to small plots as well as to large areas. The sensor(s) can be hand-held, but also mounted in aircraft or earth orbiting satellites. Particularly this last option has induced extensive further research.

The development of the approach is well documented in MILLER & PEARSON (1971), PEARSON & MILLER (1972) and TUCKER et al. (1975). The technique is based on the characteristic reflectance properties of green living plants. The plant pigments (mainly chlorophylls) absorp solar irradiance in the red band of the spectrum. The more green plant material present, the higher the amount of pigments and absorption and the less the reflected (measured) energy in this band. Reflection in the near infra-red section of the spectrum increases by increased amount of biomass. In this band absorption is low and multiple reflection causes a measurable increased reflection at higher amounts of green vegetation. For theoretical considerations and experimental evidence reference can be made to KNIPLING (1970), WOOLLEY (1971), SINCLAIR (1973), TUCKER et al. (1975) and BUNNIK (1978). A literature review is given in BECK (1979). reflected light-energy values measured in the red (R: 0.650–0.700 μm) and near infra-red (IR: 0.775–0.825 μm) bands, used in combination, particularly as $\frac{IR}{R}$ ratio, are therefore a promising measure for the amount of green vegetation.

A relatively simple, handy instrument developed on this principle is the so called biometer (bio-mass meter), described in PEARSON & MILLER (1973) and PEARSON et. al. (1976). The potential of spectral mapping of biomass following this principle from aircraft was used by MCNAUGHTON (1976) in East Africa and an airborne multispectral scanner application was reported in PEARSON & MILLER (1972) and PEARSON et al. (1976). The feasibility of band ratio biomass estimation from space platforms (Landsat) was demonstrated amongst others by CARNEGGIE et al. (1975), HAAS et al. (1975) and in MAXWELL (1976). Recent research in this field also deals with separate estimation of live wet (green) biomass and dry (brown) plant material (TUCKER 1977a, b, 1980).

A main shortcoming for extrapolation of the promising research results sofar reported is the limited variation in types of vegetation in which the tests have been carried out. The work of Pearson, Miller and Tucker (see reference list) was done in a short prairie grass (*Bouteloua gracilis*) and other work also mostly relates to more or less open gramineous vegetation (CARNEGGIE et al. 1975; HAAS et al. 1975; McNaughton 1976; Maxwell 1976). Before general operational use of the technique can be recommended tests should be made under a variety of conditions and in a wide range of floristically and physiognomically different vegetation types.

The present paper reports results of such work in The Netherlands. The data should be regarded a first step for an evaluation of the applicability of the technique for semi-natural vegetation in The Netherlands and similar conditions elsewhere, rather than a final judgment based on conclusive experiments. Further research is in progress.

2. MATERIALS, METHODS AND EQUIPMENT

For the spectral reflectance measurements use was made of a sentitive, portable light meter (United Detector Technology, no. UDT-80X) consisting of a sensor part and a signal processor with digital reading. The sensor was mounted on a tripod for observations from a height of 55 cm. When the vegetation was higher, the sensor was placed well above the highest vegetation. The top angle of measurement was 42°, at 55 cm resulting in a measured surface area of 1400 cm^2. With two filters subsequently fixed to the sensorhead, the readings in the red and near infra-red narrow wavelength bands with peaks at 0.675 µm and 0.800 µm, respectively, were produced (*fig. 1*). After the readings the vegetation of a quadrat of 0.25 × 0.25 m^2 was clipped. The harvested vegetation was put in a nylon bag and after separation of green and brown (dead) material in the laboratory fresh weight of the green material was determined. Dry weight of the samples was taken after 16 hours drying at 70°C. For each sample plot height and estimated cover (%) was recorded before clipping.

At three occasions repeated measurements were made between 9.00 and 17.00 hrs, a.o. under shady conditions, to record the influence of the changing angle of

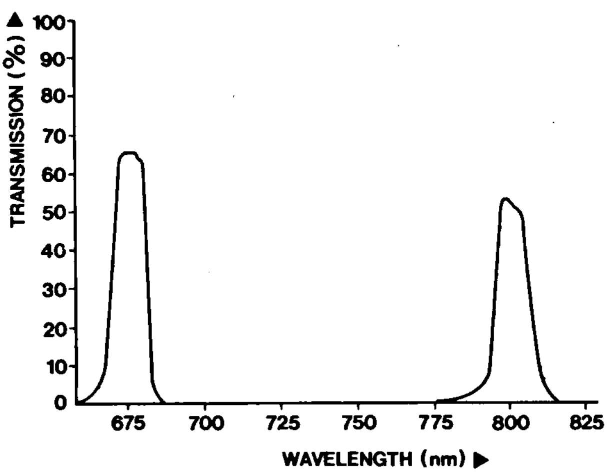

Fig. 1 Transmission characteristics of the two filters.

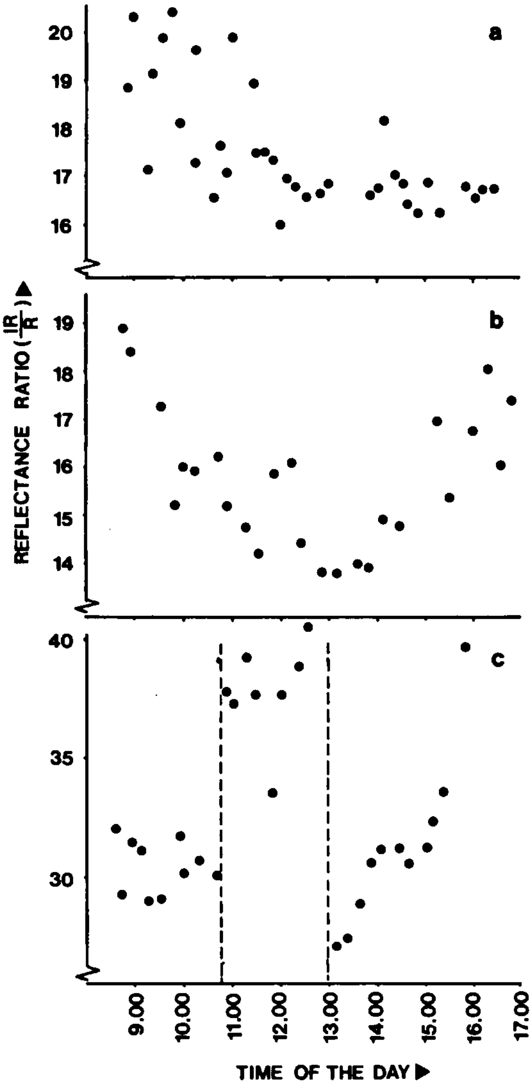

Fig. 2. Measured reflectance ratio values between 9.00 and 17.00 hrs for three sets of conditions: a. Mown lawn, 10 cm high grass cover of 95%, some clouds, 7 July 1977; b. Lawn without flowers, 15 cm high grass cover of 95%, few cirrus clouds, 18 May 1977; c. Vegetation cover of *Holcus lanatus* and *Equisetum arvense*, 30 cm high and closed cover, from 9.00–10.00 clouds, between 11.00 and 13.00 sample plot shaded by trees, 15 June 1977.

incoming radiation and of the shade (*fig. 2*). In four different vegetation types reflection values before and after (artificial) wetting of the vegetation surface was determined (*table 2*). For an idea of the influence of the presence of (brightly coloured) flowers measurements in the vegetation before and after removal of

Table 1. Brief characterization of the eleven stands in which measurements were carried out. All dates trefer to 1977.

1. Open *Sphagnum – Anthoxanthum* vegetation
Closed cover of *Sphagnum* spp. with a very open herbaceous layer consisting amongst others of *Carex* spp. (mainly *C. hudsonii*), *Juncus* spp., *Anthoxanthum odoratum*, *Drosera rotundifolia* and some *Phragmites australis* and low, mown *Salix* spp. seedlings. Reference: Type 11 in Bergmans (1975). Location: Stobberibben near Kalenberg.

Dates of observation:	15/4	9/4	3/6	24/6	4/7
Average height (cm):	10	20	40	50	100
Maximum height (cm):	40	40	65	75	100
Cover of mosslayer (%):	95	95	95	95	95
Cover of herblayer (%):	5	10	20	20	20

2. Open *Typha – Phragmites* vegetation
Well developed moss layer of mainly *Scorpidium scorpioides* and an open herbaceous layer with some *Carex* spp. (mainly *C. diandra* and *C. hudsonii*) and *Juncus* spp., particularly *J. subnodulosus*. Regularly scattered occurrence of *Phragmites australis* and *Typha angustifolia*. Reference: Type 4 in Bergmans (1975). Location: Stobberibben near Kalenberg.

Dates of observation:	15/4	9/5	3/6	24/6	4/7
Average height (cm):	10	20	45	70	95
Maximum height (cm):	40	40	65	70	95
Cover of mosslayer (%):	75	70	70	70	70
Cover of herblayer (%):	5	20	30	30	30

3. Dense *Phragmites* vegetation
Dense stand of *Phragmites australis* with the moss *Calliergonella cuspidata*. Some *Carex hudsonii*, *Lathyrus palustris* and *Cirsium palustre*. Reference: Type 6 in Bergmans (1975). Location: Stobberibben near Kalenberg.

Dates of observation:	15/4	9/5	3/6	24/6	4/7
Average height (cm):	15	40	85	130	150
Maximum height (cm):	40	60	100	150	200
Cover of herblayer (%):	40	70	80	80	80

4. *Molinia* vegetation
Virtually monospecific stand of *Molinia caerulea*, no moss layer, dead *Molinia* material on the soil surface. Reference: Type 16 in Bergmans (1975). Location: Stobberibben near Kalenberg.

Dates of observation:	15/4	9/5	3/6	24/6	4/7
Height (cm):	11	11	15	25	30
Cover dead material (%): seen from above	95	95	60	5	5
Cover live material (%): seen from above	0	0	40	95	95

5. Vegetation of high *Carex* spp.
Homogeneous cover of mainly *Carex acuta* and *C. aquatilis*. Reference: described in detail in Boedeltje (1976). Location: De Kappersbult, Drentse A area.

Dates of observation:	25/4	13/6	4/7
Height (cm):	20	50	65
Cover (%):	40	80	80

6. Dense vegetation of *Holcus lanatus*
Dense (closed), virtually monospecific cover of this species. Reference: described in Boedeltje (1976). Location: Sandy areas in De Kappersbult, Drentse A area.

Dates of observation;	2/5	16/5	13/6	1/7
Height (cm):	10	20	50	70
Cover (%):	90	90	90	95

7. Open vegetation of *Glyceria maxima*
A rather high vegetation of only this species. Growth development appeared to be not optimal during the season, indicated by brown leaftips and retarded growth compared to adjacent areas. Reference: Area 20 in LEEMBURG (1974). Location: Near Oudemolen, Drentse A area.

Dates of observation:	25/4	23/5	13/6
Average height (cm):	10	20	55
Maximum height (cm):	25	35	55
Cover (%):	25	30	35

8. Vegetation of low *Carex* spp.
The stand consists of low *Carex* spp. (*C. nigra* and *C. panicea*), grasses (mainly *Anthoxanthum odoratum* and *Agrostis canina*) and low forbs such as *Lychinis flos-cuculi* and a moss layer of mainly *Rhytidiadelphus squarrosus*.

Dates of observation:	16/5	13/6	4/7
Average height (cm):	5	20	30
Maximum height (cm):	20	40	50
Cover (%):	80	90	95

9. Vegetation of a species-rich meadow
An annually mown meadow with *Carex acutiformis* as dominant and many other species, such as *Rumex acetosa, Plantago lanceolata, Lychnis flos-cuculi, Filipendula ulmaria* and *Anthoxanthum odoratum*. Reference: Area 50 in GROOTJANS (1976). Location: Near Gasterense Diep, Drentse A area.

Dates of observation:	25/4	16/5	13/6	4/7
Average height (cm):	10	15	45	55
Maximum height (cm):	20	30	60	75
Cover (%):	75	95	95	100

10. Mixed vegetation of tall forbs
A mixture of tall species such as *Urtica dioica, Anthriscus sylvestris, Filipendula ulmaria, Heracleum sphondylium, Glyceria maxima* and *Galium aparine*. Reference: Area 53 in GROOTJANS (1976). Location: Near Gasterense Diep, Drentse A area.

Dates of observation:	25/4	16/5	13/6	4/7
Average height (cm):	20	25	100	150
Maximum height (cm):	30	120	150	200
Cover (%):	70	75	95	95

11. Vegetation of low grasses and forbs
A cover of many species, including *Plantago lanceolata, Juncus acutiflorus, Anthoxanthum odoratum, Agrostis stolonifera* and *Orchis majalis*. Reference: Described in detail in LEEMBURG (1974). Location: De Burgvollen, Drentse A area.

Dates of observation:	2/5	23/5	17/6	4/7
Average height (cm):	6	17	60	70
Maximum height (cm):	10	50	70	90
Cover (%):	75	75	90	100

the flowers in four types were made (*table 3*). Between April and July 1977 a large number of sample data were collected in 11 different vegetation types at three to five different dates. The types are characterized in *table 1*. Nomenclature is after HEUKELS & VAN OOSTSTROOM (1977). Data from the spectral measurements and the clipping and weighing were plotted in scatter diagrams. With a programmable pocket calculator the simple correlation coefficient (r) was determined as an indicator to show how well linear equations would fit the data. In addition, a first order regression analysis was carried out (Y = aX + b) with the $\frac{IR}{R}$ ratio as

Table 2. Influence of a wet versus dry vegetation surface on the reflectance ratio, as recorded in four stands of widely differing vegetation.

Type of vegetation	Reflectance ratio			
	Before wetting	After wetting	Difference abs.	Difference %
Short grass (lawn)	15.5	16.3	0.8	+ 5
Holcus lanatus stand (35 cm)	33.3	31.4	1.9	− 6
Urtica dioica stand (50 cm)	52.8	68.5	15.7	−30
Heracleum sphondylium rosettes	44.6	48.0	3.4	− 8

independant variable and wet and dry aerial biomass as dependant variables (*table 4*).

3. RESULTS AND DISCUSSION

3.1. Sun angle and shade

The reflection coefficient for most types of vegetation changes with the angle of the sun. Minimum values are found when the sun approaches its zentih and higher values as the sun descends. In this last situation there is less multiple scattering in the canopy. This has an effect on the ratio values. *Figure 2* shows the course of the values of the $\frac{IR}{R}$ ratio between 9.00 and 17.00 hrs for three sets of conditions. In *fig. 2a* the measurements of the very homogeneous smooth cover of a mown lawn of 10 cm hight and 95% cover show irregularity between 9.00 and 12.00 hrs, but a more consistent value from 12.00 to 16.00 hrs. In general, however, as can be seen from the *figs. 2b* and *2c* the values change with the angle of incoming radiation.

EGBERT & ULABY (1972) showed that under a high sun angle a grass canopy acts as a reasonable Lambertian reflector. Under such conditions the observation angle (between the vertical – zenith – and the direction of observation) has relatively little influence on the measured reflection intensity. At low sun angles

Table 3. Influence of the presence of brightly coloured parts (flowers, coloured leaves, etc.) on the reflectance ratio, demonstrated for four stands with different dominant flowering species

Dominant flowering species	Red band		Infra-red band		Ratio	
	Before removal flowers	After removal flowers	Before removal flowers	After removal flowers	Absolute difference	Percentage difference
Bellis perennis	12.52	1.13	92.0	16.8	7.6	+ 104
Ranunculus acer	1.11	0.89	14.6	26.4	16.5	+ 125
Lychnis flos-cuculi	0.43	0.28	9.5	11.3	18.1	+ 48
Holcus lanatus	5.00	2.92	64.2	55.2	6.1	+ 48

Table 4. Correlation coefficients and regression equations established for the elven stands in which periodically measurements of the reflectance ratio and aerial biomass were carried out. (n = total number of observations, r = correlation coefficient, a and b = values for the linear regression equation: Aerial Biomass (in g/0.0625 m^2) = a.Ratio + b)

Vegetation (type of stand)	fresh/dry	n	r	a	b
1. Open *Sphagnum – Anthoxanthum*	dry	32	0.91	0.63	–1.16
	fresh	32	0.90	2.00	–2.67
2. Open *Typha – Phragmites*	dry	32	0.95	2.63	–7.26
	fresh	32	0.89	7.10	–15.40
3. Dense *Phragmites australis*	dry	32	0.91	0.88	4.45
	fresh	32	0.79	2.75	30.49
4. *Molinia caerulea*	dry	30	0.95	0.66	–0.88
	fresh	30	0.94	1.59	–3.40
5. High *Carex* spp.	dry	24	0.92	0.82	–5.40
	fresh	24	0.91	2.20	–4.03
6. Dense *Holcus lanatus*	dry	22	–0.06	–0.06	13.10
	fresh	22	–0.14	–0.47	60.42
7. Open *Glyceria maxima*	dry	24	0.82	0.87	0.95
	fresh	24	0.75	2.73	14.40
8. Low *Carex* spp.	dry	21	0.88	1.57	–15.59
	(fresh	14	0.48	4.12	–143.08)
9. Species-rich meadow	dry	19	0.85	0.75	–0.95
	fresh	19	0.91	3.20	–7.31
10. Mixed tall forbs	dry	18	0.67	0.78	0.33
	fresh	18	0.65	4.95	10.75
11. Low grasses and forbs	dry	21	0.96	0.59	1.64
	fresh	21	0.97	3.20	–5.21

the "diffuse" character of the reflection changes in a more or less "mirror" character (SUITS 1972). Then the angle of azimuth (between observation direction and sun direction projected in a horizontal plane) becomes of great importance. At the zero value for this angle an observation position with a minimum of shade is possible. The importance of avoiding shade measurements is illustrated in *fig 2c* where the measured plot was shaded by tree leaves between 11.00 and 13.00 hrs, resulting in much higher ratio values. This is an addition-effect. The measured values not only represent the herbaceous canopy but to some extent (transmitted light) also the tree leaf canopy. At zero azimuth position vegetation structure (leaf positions etc.) determines the reflection readings under a certain observation angle. For a general application of the technique one should aim at an observation angle for which the variation caused by leaf positions is minimal. WARREN-WILSON (1965) and BUNNIK (1978) have investigated this point and an observation angle of 50–55° seems optimal (see also BECK 1979).

3.2. Wet versus dry vegetation surfaces

The influence on the reflectance ratio of leaf surfaces being wet can be seen from *table 2*. No major differences were found except for the *Urtica dioica* stand. The impression was that these differences could at least partly be explained by changes in leaf position under the weight of the water. It should be noted that the in 3.1. argued optimal angle of observation of 50–55° was at the time of observation not yet applied. All reported measurements were made from above in a vertical position.

3.3. Presence of brightly coloured parts

Some measured ratio values before and after removal of flowers in four stands are presented in *table 3*. No accurate data on the cover of the coloured flowers have been collected, but the order of magnitude of the changes in the ratio values (48–125%) clearly shows the disturbing effect. The conclusion is the imperative removal of brightly coloured parts in this type of observations. It may be pointed out that only for small sample plots this is feasible. It was for instance done in all situations reported under 3.4. in this study. For operational large area (scanning) applications from aircraft or satellite this aspect may prove to be a main disturbing factor for certain vegetation types under particular phenological conditions.

3.4 Application in different types of vegetation

Scatter diagrams of the results of the measurements in six of the 11 vegetation types (or better "stands" representing certain types) are shown in *fig. 3*. The established correlation coefficients and a and b values for the linear regression equation (Aerial Biomass = a.Ratio + b) are given in *table 4*. The general positive, often high, correlation between the reflectance ratio and the aerial green biomass (fresh and dry) is thereby well illustrated. The unduly high values of the established correlation coefficients must mainly be attributed to the positions of the clustered values of the measurements at the different dates (*fig. 3*). Clear linear correlations within the clusters are non-existent to poor, with a few exceptions. The June-values of the stand of low grasses and forbs are such an exception. The picture for the eleven stands is briefly discussed below.

High correlations were found for the open *Sphagnum-Anthoxanthum* stand and the *Typha-Phragmites* stand. It should be noted that the moss layer was not included in the clipping. An equally green (bright green for the *Sphagnum* spp. and dark green for the *Scorpidium* cover) or water underground has apparently little disturbing effect, as long as it is included in the calibration. The harvested amounts of biomass were of the same magnitude. Reflection ratios for the second stand, however, were generally more than twice as high as for the first one. The picture for the third stand, a dense *Phragmites australis* cover, is not yet fully clear due to lacking data for a period of very fast growth between early May and early June. The correlation coefficient only expresses a general positive correlation between two main clusters, of April-May and June-July, respectively. In the *Molinia caerulea* stand the high positive correlation was extremely clear, for both dry and fresh weight of the vegetation material. The "cluster-effect" was here less pronounced. The species-rich meadow with *Carex acutiformis* on the contrary clearly exhibits this effect (*fig. 3*). The July data were not included in the regression equation and correlation calculations of *table 4*. They showed a completely different picture (see *fig. 4* and under 3.5.). The same

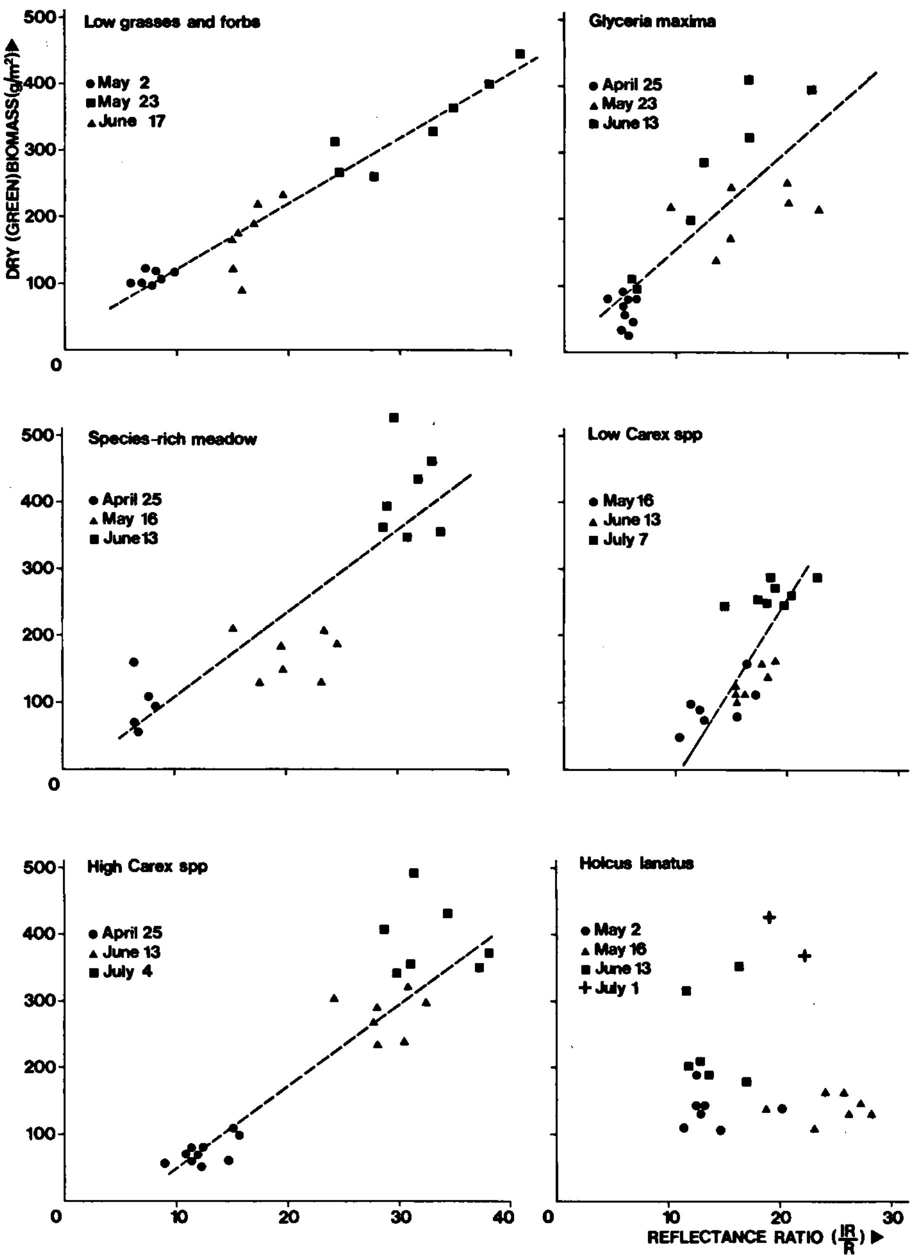

Fig. 3. Scatter diagrams and regression lines showing the relation between dry green aerial biomass and the reflectance ratio for six different types of vegetation (see *table 1*).

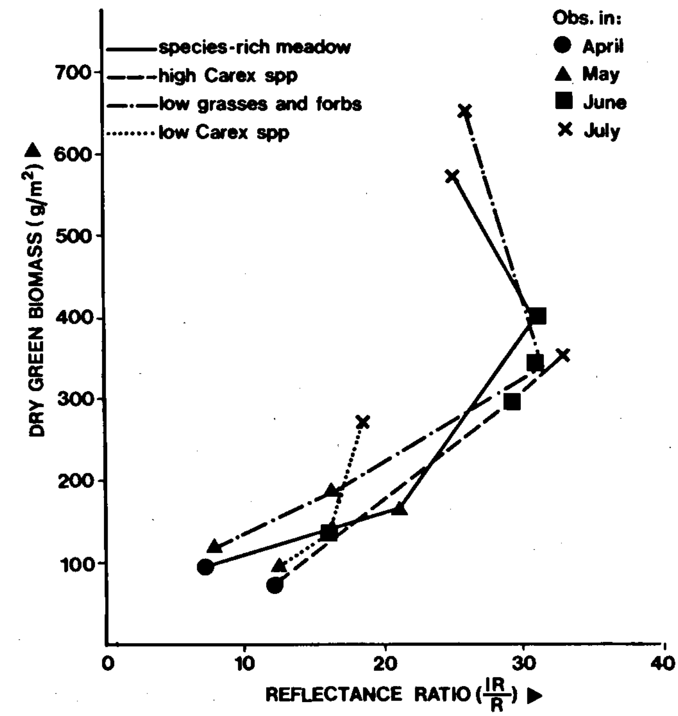

Fig. 4 Relation between the calculated mean reflectance ratio values and dry geen aerial biomass values for each date of measurement, shown for four different types of vegetation (see *table 1*).

applies for the "low grasses and forbs" stand. The correlation for the *Glyceria maxima* stand is rather poor, due to the wide scattering (high variation) of the May and June values (*fig. 3*). A same picture can be seen for the structurally somewhat similar stand of high *Carex* spp. (*fig. 3*) and the "mixed tall forbs" stand. The stand of the low *Carex* spp. had a low biomass (less than 300 g/m^2 dry weight in July) but nevertheless a positive correlation was found between the clusters. In the dense stand of *Holcus lanatus* no correlation at all was found between the ratio and the aerial biomass. The soft hairy surface of this species, giving it a greyish appearance, apparently disturbs the picture that can be seen for the other species and species combinations.

3.5. Effect of ripening (drying)

For some of the measured stands a marked increase in non-green vegetation parts was seen between June and July (N.B. apart from the flowers which were always removed before measurement). Stems and leaves turned yellowish to light brownish. Separation of the green material was not possible in these cases and the reflection ratio decreased. For two stands, the "species-rich meadow" and the "low grasses and forbs" this effect even resulted in a negative correlation, possibly according to the principle: the older – the less green – the higher the aerial biomass amount – the lower the reflectance ratio. In *fig. 4* the mean reflection ratio and biomass sample points per date are plotted for four of the measured stands. The figure illustrates the above reasoning. In a follow-up this effect requires careful study. It appears that in general the phenological stage for each type of vegetation should be given due consideration when applying the technique in the future. The introduction of a third band may be an answer to the problem (see BUNNIK 1978 and the review in BECK 1979). The work of TUCKER (1980) deals with this problem in clipped samples.

3.6 Sources of error

Apart from the considerations already mentioned some errors may have been introduced in the reported measurements, due to the equipment and technique used. Possibilities are: (i) Ideally the measurements in the two bands should have been made simultaneously and electronically processed to a ratio value, as in the biometer of PEARSON & MILLER (1973). The technique of changing filters and taking readings at a time interval may cause an error due to changing light conditions.

(ii) The digital reading of the instrument for which switching to different scales of sensitivity was required, proved a slight source of error.

(iii) Readings were taken between 10.00 and 16.00 hrs. This may cause variation due to the differences in sun angle (see 3.1.).

(iv) The observations were made vertically and not under the now recommended angle of 50–55°.

(v) An effect of partial cloudiness and therefore changing conditions, could not always be avoided.

(vi) In the biomass clippings of only 1/16 m^2 an edge-effect may have been introduced, especially in the higher vegetation types. This can be compared to the difficulties faced when establishing a rooted or shoot frequency.

(vii) In all cases the area for which the ratio was measured (at ground surface at least 1400 cm^2) was considerably larger than the area clipped (only 625 cm^2).

It may be noted that some of the above sources of error will probably be unavoidable in a future operational system.

4. CONCLUSIONS

1. The use of spectral reflectance measurements for aerial (green) biomass estimation seems feasible in a variety of structurally and floristically different vegetation types. The technique still requires an extensive testing and calibration in each type separately, whereby the phenology should be given careful consideration.
2. Measurements in the shade or of plots with large amounts of shade are of little value. This can be minimized by measurement at clear sky in the same direction as the incoming solar radiation.
3. The presence of brightly coloured parts (flowers, coloured leaves, etc.) can be a source of great errors. Whenever possible such parts should be excluded from the measurements.

4. Measurement at clear sky from above, or in general under an angle of observation of 50–55° gives least interference with vegetation structural differences (literature data, see BECK 1979).
5. Measurements should be taken as far as possible at about the same time of the day and under similar weather conditions.
6. With non-optimal equipment and vertical measurement the best linear positive correlation between the band ratio and the aerial biomass was found for vegetation with the following characteristics (i) many vertical elements and little horizontal overlap, (ii) cover less than 80%, (iii) not too high a vegetation, (iv) no non-green, coloured parts. This picture fits well to most of the vegetation types to which the technique was applied, sofar reported in the literature (see Introduction).
7. With further sensor development, testing and calibration, a fast and useful technique for aerial biomass estimation seems at hand.

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