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Relationship between light interception, ground cover and leaf area index in potatoes

D. M. FIRMAN AND E. J. ALLEN[2]

[1]*Department of Applied Biology, Pembroke Street, Cambridge CB2 3DX, UK*
[2]*Cambridge University Farm, Huntingdon Road, Cambridge, UK*

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SUMMARY

In field studies of two varieties in Cambridge, UK, in 1985 and 1986, the percentage of total incident radiation intercepted by potato canopies with complete ground cover was as low as 80% for some plots but approached 100% in dense canopies. Although percentage ground cover is useful for assessing canopy growth, it is not wholly suitable for estimating light interception and may lead to serious errors in calculation of efficiency of conversion into dry matter.

INTRODUCTION

Crop growth is now frequently analysed in terms of the interception of radiation and efficiency of conversion into dry matter (e.g. Biscoe & Gallagher 1977; Russell & Ellis 1988; Shibles & Webber 1965; Williams *et al.* 1965) and growth of potato crops has been investigated in this way (Burstall & Harris 1986; Sale 1973; Scott & Wilcockson 1980). In order to calculate the efficiency of conversion of light energy into dry matter, it is necessary to measure the amount of light intercepted by the crop and crop dry matter content. Efficiency is often presented in units of dry weight of plant per unit of total radiation intercepted (usually g/MJ) rather than per unit of photosynthetically active radiation, PAR (0·4–0·7 μm). Crop dry weight can be readily estimated by harvesting and drying samples from the crop, while measurement of light interception requires the use of solarimeters placed above and beneath the crop. Burstall & Harris (1983) suggested that use of solarimeters has disadvantages in terms of cost and accuracy and that the use of percentage ground cover (measured with a grid) could be advantageous. Burstall & Harris found a close linear relationship between percentage ground cover (GC) and percentage light interception measured by solarimeters (LI) with a slope close to unity, although slightly higher for two maincrop varieties Cara and King Edward (LI = 0·956GC − 4·95) than for Wilja, a second-early variety (LI = 0·933GC − 6·71).

Percentage ground cover measurements have been used by a number of authors to estimate light interception and it has been commonly assumed that 100% ground cover is equivalent to 100% light interception. Van der Zaag (1984) assumed a relationship between ground cover and light interception whereby ground cover should be multiplied by a factor of 1 to give light interception when ground cover was < 10 or 100%. The multiplication factor used by Van der Zaag increased with intermediate ground cover, so that at 40% ground cover the factor was 1·3. Burstall & Harris (1986), Fahem & Haverkort (1988) and Haverkort & Harris (1986) used a linear relationship between ground cover and light interception whilst Millard & Marshall (1986) assumed a 1:1 relationship between ground cover and light interception to calculate efficiency of dry matter production. The published information does not really allow any good test of whether there is a 1:1 relationship between ground cover and light interception or whether the relationship may be altered by factors such as agronomy, variety and season as is the relationship between leaf area index (LAI) and light interception. For a range of crops, Monteith (1969) calculated that the LAI at which only 5% of light (PAR) was transmitted by the crop, L_5, ranged from 2·9 in planophile species such as clover to 11·5 in erect-leaved plants such as perennial ryegrass. Kurana & McLaren (1982) found that light interception (PAR) increased linearly with LAI in potatoes up to *c.* 2·25 and that L_5 was achieved at a LAI of 4. Burstall & Harris (1983) fitted an inverse polynomial to their data of light interception and LAI which indicates an increase in light interception up to a LAI of 8, whilst the data presented by Scott & Wilcockson (1978) indicated that for LAI > 3 there is little increase in light interception.

Measurement of ground cover provides a simple and repeatable method of describing the growth of a canopy and it is important that the relationship between ground cover and light interception is comprehensively established so that its use in describing leaf growth, and especially in calculation of efficiency of radiation conversion, is established. This paper presents results from experiments where ground cover, light interception and leaf area index were measured, and the relationships between these three measures of the canopy were compared with results from other workers to elucidate the use of ground cover as a measure of amount of light intercepted.

MATERIALS AND METHODS

Two experiments were carried out on the Cambridge University Farm, UK, in 1985 (Expt 1) and 1986 (Expt 2). Treatments comprised all combinations of three rates of N (0, 90 or 180 kg N/ha) and the varieties Estima and Pentland Crown; in Expt 2 there were three dates of planting, 14 March, 11 April and 12 May. Fertilizer at 109 kg P, 207 kg K, 60 kg Mg/ha and N according to the treatments was applied by hand over the open ridges at planting. Plots consisted of four rows, 72 cm apart with plants spaced at 25 cm along the rows; observations were made on the centre two rows. Ground cover was recorded at least once a week using a grid of 72 × 50 cm divided into 100 equal rectangles. Two measurements were made in each plot by counting the number of rectangles more than half filled with green leaf. Readings were taken over the area of the plot used for destructive sampling, therefore the area measured was nearer the end of the plot for later readings. The light intercepted by the plants was measured using tube solarimeters (Szeicz *et al.* 1964) with 858 × 22 mm detectors (Delta T Devices Ltd). A pair of solarimeters wired together were placed across the centre rows, *c.* 1·5 m from the end of the plot with the top of the solarimeter < 5 cm above the ridge, in one replicate of each treatment before plant emergence. The orientation of the tubes (at right angles to the rows) was approximately N–S in 1985 and E–W in 1986. Tube solarimeters were individually calibrated against a Kipp solarimeter (Kipp & Zonen, Netherlands) placed in an open location by comparing daily sums of readings taken every 5 min for several days before the crop emerged. Throughout the season, solarimeter readings were automatically logged and the percentage of total incident radiation intercepted by the crop was calculated for each day as the sum of 24 hourly solarimeter readings divided by the corrected sum of the Kipp solarimeter readings taken every 5 min. Leaf area index was calculated from harvests of four plants from each plot at intervals during growth. Harvests were dug from one end of the plot sequentially, leaving a discard plant between successive samples. Leaves were stripped from the petioles and leaf area was estimated by punching out from the leaf sample (which included the midrib) fifty discs of 2·54 cm^2 which were dried and weighed separately from the main sample (Watson & Watson 1953; Bremner & Radley 1966).

Readings of light interception were compared with ground cover and LAI measurements from when leaves first started to cover the tube solarimeters until about the time of maximum standing crop dry weight, determined by growth analysis, so that the relationship was not influenced by values of ground cover obtained before leaves reached the height of the solarimeters or by lodging and dead leaves during senescence. Readings of light interception were compared with ground cover and LAI for the individual plots with solarimeters rather than the mean of all replicates.

RESULTS

Readings of ground cover > 80% were invariably higher than percentage light interception so that, at high ground cover, percentage light interception decreased below the 1:1 line (Fig. 1). Linear regressions of light interception and ground cover gave a reasonably close fit and slopes tended to be steeper with the highest rate of N application (0·804 in Estima and 0·836 in Pentland Crown for Expt 1) than at lower N (0·661–0·712) but could not be compared by analysis of variance as solarimeters were placed in one replicate only.

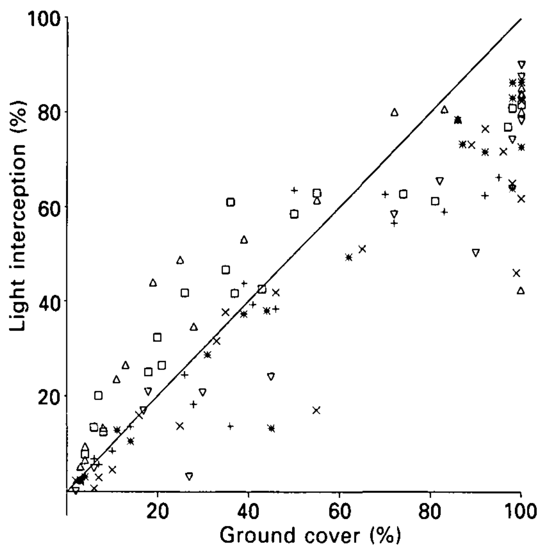

Fig. 1. Relationship between ground cover and light interception in two potato varieties in Expt 1. (+) Estima, 0 kg N/ha; (×) Estima, 90 kg N/ha; (*) Estima, 180 kg N/ha; (□) Pentland Crown, 0 kg N/ha; (△) Pentland Crown, 90 kg N/ha; (▽) Pentland Crown, 180 kg N/ha, Fitted line $y = x$.

Table 1. *Maximum recorded values of light interception (LI) and ground cover (GC) by two potato varieties*

Date of planting	N applied (kg/ha)	Estima LI	Estima GC	Pentland Crown LI	Pentland Crown GC
19 April 1985	0	69	95	81	98
	90	83	100	85	100
	180	86	100	90	100
14 March 1986	0	60	75	82	95
	90	85	98	85	98
	180	85	98	90	100
11 April 1986	0	71	85	—	—
	90	81	98	85	100
	180	88	100	88	100
12 May 1986	0	74	95	65	85
	90	80	100	85	100
	180	90	100	91	100

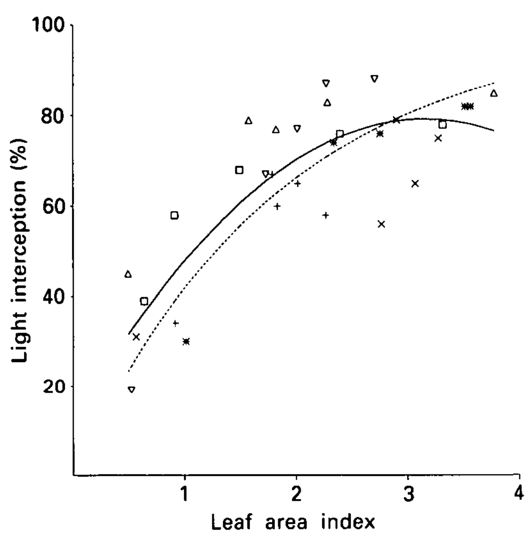

Fig. 2. Relationship between leaf area index of potato plants and light interception in Expt 1. Symbols as in Fig. 1. Fitted lines: (----) $(100-y)/100 = e^{-0.543x}$, r^2 adjusted = 0·497; (——) $y = 12{\cdot}1 + 42{\cdot}6x - 6{\cdot}74x^2$, r^2 adjusted = 0·690.

Comparison of the maximum values of light interception throughout growth (Table 1) indicated that, even with the dense canopy produced by a maincrop variety grown with a high rate of N, light interception was not much more than 90%. The ground cover readings at the time of maximum light interception (Table 1) were 98 or 100% for all plots with applied N but light interception was as low as 80% for some plots which received no N, and ground cover of 95% was associated with light interception as low as *c.* 70%.

The relationship between LAI and light interception used by Monteith (1969) ($T_L = \exp(-KL)$, where T_L is the fraction of light transmitted at LAI L, and K is the coefficient of extinction, and a quadratic curve were fitted to the data from Expt 1 (Fig. 2). The data indicated that there was little increase in percentage light interception for LAI > 3.

DISCUSSION

The results suggest that the use of ground cover to predict light interception may be inaccurate because readings of ground cover approaching 100% are sometimes associated with values of percentage total radiation interception of only 80%, although, with dense canopies, radiation interception approached 100%. The difference in light interception of crops with nearly complete ground cover but of contrasting LAI may lead to apparent differences in calculated efficiency of dry matter production if efficiencies are calculated using ground cover. Van der Zaag (1984) compared a number of crops which had an optimum growth pattern and found that actual yields were lower than potential yields, although differences in ground cover of the crops could not account for the reduction in yield. However, reduction in light interception and yield could result if the crops produced complete ground cover but had a low LAI. For calculating efficiency in terms of photosynthetically active radiation, the errors are likely to be reduced for, although 50% of incident radiation is PAR, leaves transmit *c.* 7% PAR and 25% of total radiation (Monteith 1969) so that the proportion of PAR under the canopy is lower than in incident radiation. Nevertheless, at 100% ground cover, values of PAR transmitted will vary somewhat with the density of the canopy.

Loss of sensitivity of tube solarimeters occurs when the light is parallel to the tube axis, but Szeicz *et al.* (1964) found that, for a solarimeter aligned E–W, variation in sensitivity between the azimuth angles of 30–170° was only ±3%, therefore significant loss of sensitivity only occurred when light intensity was low at sunrise and sunset. For a tube aligned N–S, the variation in sensitivity could lead to some inaccuracy; calibration of solarimeters *in situ* over several complete days should reduce this and, when ground cover is nearly complete, direct sunlight would be of negligible significance so that tube orientation should not affect the values of maximum light interception obtained. The dimensions and positioning of solarimeters are important in crops grown in rows because, in order to sample a representative area, the detector would ideally be a multiple of row width and interplant spacing so that readings are not biased by clumping of stems along the ridge. Such dimensions are impractical for a tube solarimeter in many cases and, in these experiments bias was minimized by using detectors only slightly longer than the row width, placed across the rows at a random position in relation to that of the plants in the row. Solarimeters may underestimate light intercepted if green leaves are present below the solarimeter but this usually only occurs during the early stages of growth and not at canopy closure. Ground cover measurements can be taken over a much larger area of the crop than is sampled by tube solarimeters but are taken much less frequently than solarimeter readings and may be subject to errors due to any diurnal trends in ground cover. On days of high evapotranspiration, loss of turgidity of leaves can result in 5% or more reduction in ground cover late in the day so that, if ground cover readings are usually taken before noon (as in these experiments), values tend to be higher than the daily mean.

The slopes obtained for regression of light interception and ground cover were lower than those reported by Burstall & Harris (1983) but their slopes were calculated using a number of values of 0% light interception, thus forcing a negative intercept and increasing the slope. Burstall & Harris also had more-dense canopies, up to a LAI of 8, and the distribution of stems may have been more clumped as their interplant and row spacings were wider than in these experiments. Nevertheless, the data of Burstall & Harris confirm that light interception is not constant at 100% ground cover, as this ranged from *c.* 80 to 95% for their data, and that light interception at high ground cover is consistently lower than the assumption of a 1:1 relationship predicts.

Complete ground cover may be achieved at a low LAI but light interception continues to increase with the density of the canopy beyond 100% ground cover as sunflecks and diffuse radiation are less able to penetrate. The relationship between LAI and light interception was similar to those presented by Scott & Wilcockson (1980) and Kurana & McLaren (1982) in that light interception increased rapidly with increasing LAI up to *c.* 2·5 and that light interception increased little above LAI 3. Increase in light interception up to a LAI of 8 as found by Burstall & Harris (1983) may be due to differences in stem and leaf distribution. Although a quadratic curve (Fig. 2) gave a reasonable fit to the data from Expt 1, increase in LAI > 4 should continue to increase light interception as suggested by an exponential curve of the form used by Monteith (1969).

Measurement of ground cover in field crops and experimental plots provides useful information on rate of canopy growth and, as readings require simple equipment, considerable information can be obtained to compare growth of different crops. A graph of ground cover over the season can be compared with that of an 'ideal' crop to explain patterns of growth, and critical data, such as the interval from emergence to maximum ground cover, can be compared for contrasting crops. The use of ground cover for calculation of efficiencies of dry matter conversion however, is subject to serious inaccuracies and should be avoided, except where the relationships between leaf area, light interception and ground cover is known. In contrast, LAI provides a measurement of the canopy which could be used to estimate light interception and efficiency because light interception varies with LAI at complete ground cover.

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REFERENCES

Biscoe, P. V. & Gallagher, J. N. (1977). Weather, dry matter production and yield. In *Environmental Effects on Crop Physiology* (Eds J. Landsberg & C. V. Cutting), pp. 75–100. London: Academic Press.

Bremner, P. M. & Radley, R. W. (1966). Studies in potato agronomy. II. The effects of variety and time of planting on growth, development and yield. *Journal of Agricultural Science, Cambridge* **65**, 253–262.

Burstall, L. & Harris, P. M. (1983). Estimation of percentage light interception from leaf area index and percentage ground cover in potatoes. *Journal of Agricultural Science, Cambridge* **100**, 241–244.

Burstall, L. & Harris, P. M. (1986). The physiological basis for mixing varieties and seed 'ages' in potato crops. *Journal of Agricultural Science, Cambridge* **106**, 411–418.

Fahem, M. & Haverkort, A. J. (1988). Comparison of the growth of potato crops grown in autumn and spring in North Africa. *Potato Research* **31**, 557–568.

HAVERKORT, A. J. & HARRIS, P. M. (1986). Conversion coefficients between intercepted solar radiation and tuber yields of potato crops under tropical highland conditions. *Potato Research* **29**, 529–533.

KURANA, S. C. & MCLAREN, J. S. (1982). The influence of leaf area, light interception and season on potato growth and yield. *Potato Research* **25**, 329–342.

MILLARD, P. & MARSHALL, B. (1986). Growth, nitrogen uptake and partitioning within the potato (*Solanum tuberosum* L) crop, in relation to nitrogen application. *Journal of Agricultural Science, Cambridge* **107**, 421–429.

MONTEITH, J. L. (1969). Light interception and radiative exchange in crop stands. In *Physiological Aspects of Crop Yield* (Ed. J. D. Eastin), pp. 89–113. Wisconsin: American Society of Agronomy.

RUSSELL, G & ELLIS, R. P. (1988). The relationship between leaf canopy development and yield of barley. *Annals of Applied Biology* **113**, 357–374.

SALE, P. J. M. (1973). Productivity of vegetable crops in a region of high solar input. II. Yields and efficiencies of water use and energy. *Australian Journal of Agricultural Research* **24**, 751–762.

SZEICZ, G., MONTEITH, J. L. & DOS SANTOS, J. M. (1964). Tube solarimeter to measure radiation among plants. *Journal of Applied Ecology* **11**, 169–174.

SCOTT, R. K. & WILCOCKSON, S. J. (1980). Application of physiological and agronomic principles to the development of the potato industry. In *The Potato Crop: The Scientific Basis for Improvement* (Ed. P. M. Harris), pp. 678–704. London: Chapman and Hall.

SHIBLES, R. M. & WEBBER, C. R. (1965). Leaf area, solar radiation interception and dry matter production by soybeans. *Crop Science* **5**, 575–582.

WATSON, D. J. & WATSON, M. A. (1953). Comparative physiological studies on the growth of field crops. III. The effect of infection with beet yellows and beet mosaic viruses on the growth and yield of the sugar beet crop. *Annals of Applied Biology* **40**, 1–37.

WILLIAMS, W. A., LOOMIS, R. S. & LEPLEY, C. R. (1965). Vegetative growth of corn as affected by population density. I. Productivity in relation to interception of solar radiation. *Crop Science* **5**, 211–215.

ZAAG, VAN DER, D. E. (1984). Reliability and significance of a simple method of estimating the potential yield of the potato crop. *Potato Research* **27**, 51–73.