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Can reflective ground cover enhance fruit quality and colouration?

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Abstract
White reflective ground cover was spread in mid September on the grass strips on both sides of the tree rows of seven-year-old cv. Braeburn apple on M9 rootstock to improve light utilisation in the orchard. Apple trees in uncovered grass strips served as controls. The maturity and quality parameters [fruit size, fruit firmness (10.4 kg cm^{-2}), starch breakdown (score 4) and sugar content (12.6%)] of the late-ripening, bi-coloured cv. Braeburn apple fruit at harvest were unaffected by the reflective ground cover. White reflective ground cover on the grass strips improved light utilisation in the orchard in terms of fruit colouration, particularly for the lower part of the tree close to the reflective ground cover and the inner, tree-facing and down-facing, otherwise shaded sides of the apple fruit. The improved fruit colouration with reflective ground cover is attributed to increased light utilisation in the orchard. The present work showed that effective enhancement of fruit colouration with retention of good fruit quality is possible, if reflective ground cover is spread as late as mid September, i.e. only four weeks prior to harvest, in the tree alleys of the late ripening, bi-coloured cv. Braeburn apple.

Key words: Anthocyanin, apple, colour, firmness, fruit quality, light, sugar.

Introduction
Crops planted in rows are unable to utilise the overall incident radiation [8]. A large proportion of the incident light falls upon the grass alleys between the tree rows. In Western Europe, fruit colouration of bi-coloured, late ripening cultivars such as Braeburn is particularly difficult. Braeburn is a relatively new apple cultivar with increasing popularity due to its good taste, associated with large sugar and acid content, crispness and storability. Its fruits mature late in mid October, a time when incident radiation and temperature decrease. However, light utilisation of fruit tree crops can be improved by spreading reflective ground cover between the rows [1, 3]. Such reflective ground covers can delay harvest up to one week in cv. Fuji apples on M26 in regions of intense radiation such as California [1]. The reverse applies to regions of less intense incident radiation such as Western Europe and New Zealand [6]. The objective of the present work was to improve light utilisation of cv. Braeburn apple trees using reflective ground cover in order to achieve good fruit colouration with retention of good fruit quality.

Materials and Methods
Apple orchard: Seven-year-old cv. Braeburn apple (*Malus domestica* Borkh.) trees on M9 rootstock were grown at a spacing of 3.50 m x 1.20 m in North to South orientation during the 2001 growing season at Klein-Altendorf experimental station of Institut für Obstbau of Bonn University, Germany. The experiments comprised 54 apple trees in one row planted in North-South orientation. Apple trees were harvested on 20th October 2001.

Reflective ground cover: The woven white reflective polypropylene ground cover (Extenday™, type 4693) had been used once at Klein-Altendorf for ca. ten weeks in another fruit crop in the field. The three metre wide material was spread on 17 September 2001, four weeks prior to the predicted harvest date, on both sides of one tree row (27 apple trees), leaving a 0.5 m wide uncovered tree strip for the trees' water supply (Fig. 1). Another adjacent 27 apple trees in uncovered grass strips of the same row served as control. Ten trees of each treatment were selected for uniformity for further assessment.

Light reflection: Light intensities were measured as PAR (400-700 nm) on a sunny autumn day on 13 September 2001 at 45° and 90° angle 1 m above the reflective ground cover or grass respectively with a HTR-2 probe (PPSystems, Hitchin, UK). Light reflection was calculated as percentage reflected of incident light in the diurnal course.

Yield and fruit grading: Fruit of the selected 2x ten trees were subjected to commercial grading procedures to evaluate yield, fruit number and fruit weight for each tree in the experiment at harvest. An automated grader type Greefa MSE 2000 with integrated camera and computerised single fruit evaluation was used to assess size and colour of each fruit of the experiment for further statistical processing.

Fruit quality: To evaluate the influence of light reflection from the ground cover and light penetration into the tree canopy on apple colouration, fruit quality was assessed in two different parts of the canopy of the 27 selected trees. Five apple fruit from the inner, central part of the tree canopy (lower third of the tree, close to the trunk) and five fruit per tree from the outer, peripheral part of the canopy were randomly sampled. Fruit firmness was measured with an ART system (UP Products, Germany) having an integral automatic penetrometer with 10 mm diameter screwhead on two opposite sides along the fruit equator. Total soluble solids (TSS) were also determined with the ART system having a digital refractometer type Atago PR 32 (Atago, Japan). Fruit from the same batch were cut into half. These fruit halves were scored for staining after starch-iodine treatment (0 = all tissues stained black to 10 = no staining, all starch degraded).

Colour assessment: The colour development of the same five attached apple fruit from the inner, central canopy and five fruit from the outer canopy was measured *in-situ* as hue° values [5] (Table 1) non-destructively three times prior to harvest at weekly intervals with a portable spectrophotometer type Minolta CM-503d. The colour of the green side and the red side of these ten (2 x 5) fruit was measured at the fruit equator. The assessments were continued at harvest with an additional colour measurement of the down-facing side of each fruit which was marked while fruit were still on the tree before harvest.

Table 1. Colour designation in the hue scale [5].

Hue°	Colour
0° / 360°	red – violet
45°	orange
90°	yellow
135°	yellow-green
180°	blue-green
270°	blue

Statistical analysis: Data were statistically analysed using the SPSS package version 11.0 (SPSS Inc. USA). Fruit quality and colour data at harvest were analysed separately for the two positions in the tree canopy as described above. The influence of the treatment was determined using t-test with $p = 0.05$.

Results and Discussion

Yield: Yields averaged 10 kg cv. Braeburn apples per tree (data not shown), a harvest sufficient to exclude effects of low yields with excessive fruit sizes on colour development. No sunburn was observed in either of the treatments when the reflective ground cover was spread in mid-September (data not shown).

Fruit quality: There were no statistically significant differences in fruit quality at harvest between control fruit from apple trees without reflective ground cover and those exposed to reflective ground cover (Table 2). Overall, neither fruit firmness nor soluble solids nor starch breakdown were affected by the increased light reflection from white reflective ground cover between the apple tree rows. Our results confirmed previous reports [1, 3, 7] that various reflective materials used as ground cover did not affect fruit quality parameters such as firmness, sugar content, starch breakdown and acidity in apple fruit.

Table 2. Fruit quality of cv. Braeburn apple from the inner and outer tree canopy at harvest 2001 in Klein-Altendorf, Germany.

Treatment	Fruit position in tree	Streif maturity index F/(SS*SPI)	Firmness (kg cm^{-2})	Soluble solids TSS (% Brix)	Starch breakdown (1-10)
Control (uncovered)	Inner	0.20	10.5	12.1	4.6
	Outer	0.23*	10.6	12.6	4.1
Reflective ground cover	Inner	0.20	10.2	12.1	4.4
	Outer	0.25*	10.4	12.6	3.6

* statistically significant differences at $p = 0.05$

The only statistical difference in fruit quality between the treatments was in the Streif or maturity index (Table 2). Apple cv. Braeburn fruit from the outer part of the canopy of trees with ground cover had a higher Streif maturity index of 0.25 compared with 0.23 from control fruit of trees without reflective ground cover.

Colour development of ' Braeburn' apple fruit: The colour development of cv. Braeburn apples was measured non-destructively on the same ten fruit three times prior to harvest at weekly intervals and at harvest. The largest differences in colouration between trees with and without ground cover of the red side of the fruit were observed in fruits from the inner part of the canopy (Fig. 2). The colour of control fruit inside the tree canopy, shown as °hue, dropped from 84°hue three weeks prior to harvest, to 66° at harvest. By contrast, inner fruit exposed to reflective ground cover, developed a deeper red colour associated with hue values between 60°hue prior to harvest and 48°hue at harvest (Fig. 2). The colour of the green side of the control fruits from the outer part of uncovered tree rows changed from 103°hue to 95°hue at harvest (Fig. 3). With reflective ground cover, this colouration changed from 86° to 73°, associated with a larger area of visible red colouration. Fruit from the central part of the tree canopy showed similar differences in response to the ground cover, but at a higher level (Fig. 3).

Our results partly resemble those of Andris et al.[1] in California who found differences in the red side but not the green side of the cv. Fuji apple fruit. Their comparable reflective ground cover reduced hue values of the red side of apple fruit from 102° to 98° and 87° to 85° hue depending on training system. By contrast, the red side of the apple fruit in the outer canopy with hue values of 36° showed saturated red colouration, which cannot be further improved by the use of the reflective ground cover.

The influence of the white reflective ground cover on fruit colouration was most pronounced on the down-facing side of the apple fruit at harvest (Fig. 4). The down-facing side of control fruit from uncovered tree rows provided a significantly lower hue value of 96° in the outer than the 107° in the inner tree canopy (Fig. 4) which is defined as green-yellow colours and lack of red colouration. By contrast, reflective ground cover induced red colouration on the down-facing side of both fruit from the outer and inner part of the tree canopy, whose hue values of 57° and 60° were not statically different (Fig. 4).

Automated fruit grading at harvest: Apple fruit were subjected to commercial grading procedure. All fruit from apple trees exposed to reflective ground cover showed a larger percentage of top colour at harvest compared to unexposed fruit (Fig. 5). More than 34% of fruit from trees with reflective ground cover showed 75% red colouration or greater compared to 3% of untreated control fruit (Fig. 5). Ca. 20% of the untreated fruit had less than 15% red colouration, whereas only 5% of the treated fruit belonged to that category (Fig. 5). Since good fruit colouration is a major factor in marketing and pricing of many apple cultivars the use of reflective ground cover could enhance sales opportunities. This is particularly true for apple cultivars with several picks and could lead to a reduced number of picks.

Figure 1. White reflective ground cover on the grass alleys between rows of cv. Braeburn apple trees.

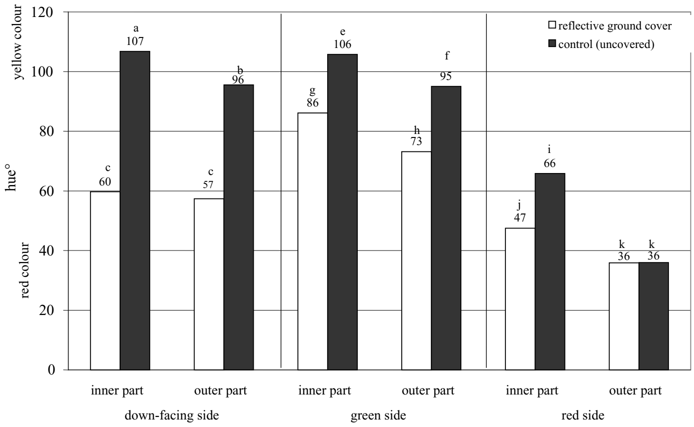

Figure 4. Colouration of all three, the red, green and down-facing side of cv. Braeburn apple fruit at harvest on 20 October 2001.

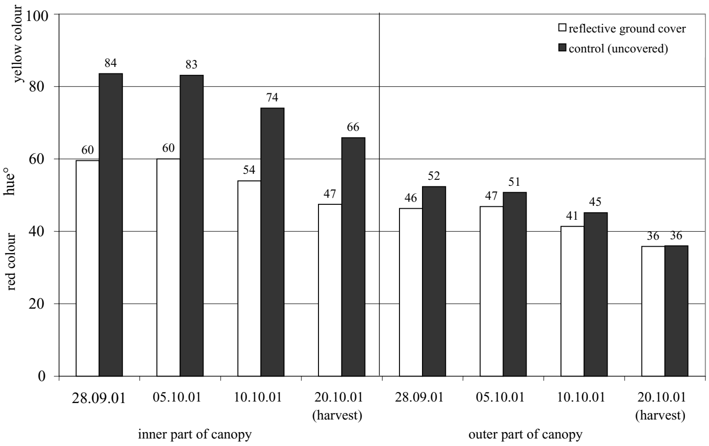

Figure 2. Red side of apple cv. Braeburn fruit from the inner and outer part of the tree canopy at three weekly intervals before and at harvest.

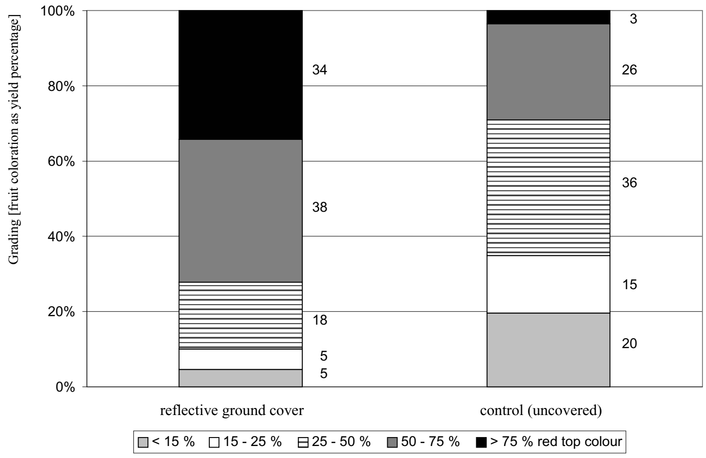

Figure 5. Colour grading of cv. Braeburn apple fruit at harvest using automated sorting machine type MSE 2000 from Greefa.

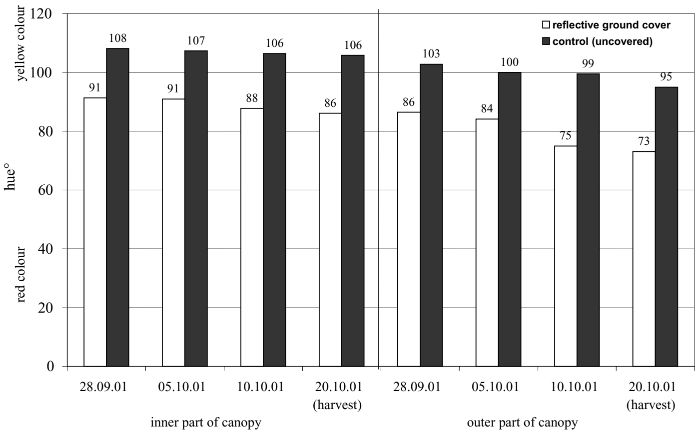

Figure 3. Green side of apple cv. Braeburn fruit from the inner and outer part of the tree canopy at three weekly intervals before and at harvest.

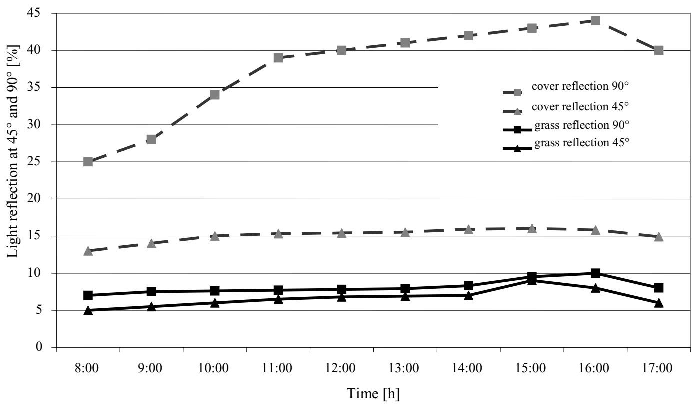

Figure 6. Diurnal course of light reflection (PAR, 400-700 nm) from the reflective ground cover and uncovered grass strips on a sunny autumn day (13 September 2001).

Light reflection, fruit colouration, light and anthocyanin synthesis: The white reflective ground cover reflected 25-45% of incident light at 90° and 14-16% at 45° compared with 9% at 90° and 5% at 45° respectively from the uncovered grass strips (Fig. 6). The reflective ground cover on the grass strips improved light utilisation in the orchard in terms of fruit colouration, particularly for the lower part of the tree close to the reflective ground cover and the inner, tree-facing and down-facing, otherwise shaded sides of the apple cv. Braeburn fruit. This effect can be explained by improved utilisation of reflected visible and possibly UV-light. Lancaster [4] reported enhanced anthocyanin synthesis in the skin of apple fruit due to a larger proportion of UV-B (280-320 nm) in incident light and consequently improved top colouration [2].

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