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The effect of nitrogen supply on specific yield and fruit quality of apple (*Malus domestica* Borkh.)

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Summary: The aim of the present study was to determine the effect of nitrogen supply on yield and fruit quality of apple cultivars and to explore the relationships between canopy density and the different fruit quality parameters.

The experiments were carried out at Kálmánháza, in Eastern Hungary in a private orchard in 2003–2004. The response of four apple cultivars ('Elstar', 'Gala Prince', 'Granny Smith', 'Idared') to different nitrogen dosages was studied. The assessed and calculated indices were: yield, fruit diameter, fruit height, shape index, fruit mass, firmness, dry matter content and colouration. The results indicated that nitrogen fertilization has a significant effect on the yield and fruit quality of apple cultivars. The calculated specific yield values were reduced by the application of nitrogen via the increase in the volume of the canopy. An opposit trend was observed for fruit diameter, fruit height and fruit weight, which increased with increasing nitrogen supply. The reduced shape index caused flattening of fruits.

However, the improvement of fruit quality via increasing nitrogen dosage is only virtual, since these dosages increase the fruit size, but firmness, dry matter content and colouration are diminished, which decreases the value of the fruits on the market.

The authors also studied the relationships between canopy density responsible for assimilation and light supply of the fruits and the different fruit quality parameters. The closest linear inversely proportional relationship was found in the case of colouration. There was a negative linear relationship between canopy density and firmness or dry matter content. The relationship between canopy density and fruit mass could be described by a quadratic polinomial function.

Key words: apple, specific yield, fruit quality, nitrogen, dry matter content, firmness, fruit diameter, fruit height shape index, fruit mass, colouration, canopy density

Introduction

There are numerous fruit quality parameters described by the literature, which vary greatly in their definition. (*Bramlage* et al.,1980; *Bünemann,* 1980; *Soltész,* 1998; *Wijs & Heij,* 2003; *Racskó* et al., 2004b). The classical definition is: "Fruit quality in a wider sense is the combination of all those characteristics that determine the fruit's suitability for fresh consumption, quick freezing, processing or improving the quality of another product (e.g. medicine, cosmetics)" (*Soltész,* 1998). Consequently, fruit quality is a relative and constantly changing category (*Soltész,* 2003).

Quality parameters are determined primarily by the characteristics of the cultivar (appearance, inner content, biological and rheological characteristics, suitability for processing) (*Glant* et al., 2004; *Racskó,* 2004b). The site requirements and agronomical characteristics of the cultivar play a major role in productivity and technology (*Stiles & Reid,* 1991; *Wargo* et al., 2003). Site characteristics promote or inhibit the realization of the genetic potential coded at molecular level (*Torben & Hansen,* 1998). Growing and plant protection conditions have a direct effect on the realization of cultivar characteristics in fruit quality by influencing the health of the fruit (*Soltész,* 1998; *Holb & Heijne,* 2001; *Racskó* et al, 2004a). It is also accepted that the year also has a decisive effect on quality (*Győri,* 1999).

Among the agrotechnical factors, nutrient supply has a great significance (*Debreczeni & Sárdi,* 1999). While the applied nutrient dosages decreased dramaticall in Hungary during the last years for economic reasons, the consumer requirements increased at a higher rate. Nitrogen has an essential role in this process (*Loch & Nosticzius,* 2004). Directly and indirectly, nitrogen supply plays a major role in determining the quality of fruits (*Magness* et al., 1948; *Fisher & Cook,* 1950; *Beattie,* 1958; *Hill-Cottingham & Lloyd-Jones,* 1975; *Goode & Higgs,* 1977; *Hansen,* 1980; *Johnson & Samuelson,* 1990; *Raese & Drake,* 1997; *Neilsen* et al., 1998; *Wargo* et al., 2003). However, its effect varies among the different species (*Sanchez* et al., 1990*; Stiles & Reid,* 1991). In the case of pome fruits, the effect on the quality of winter apples has been studied lately mainly on cv. Jonathan (*Overholser & Overley,* 1939; *Papp,* 1997). The studies were called for by the fact that the different fertilization levels resulted more and more frequently in disharmony in nutrient supply, which had disadvantageous effects on quality and storability (*Győri,* 1999).

Racskó et al. (2004b, 2005) claimed that the following statements should be considered when calculating fertilizer dosages:

- fruit size and firmness are inversely proportional,
- there is a significant linear relationship between fruit size and colouration
- and between colouration and dry matter content.

Besides one-sided, high-dosage nitrogen fertilization, firmness, colouration, vitamin C, flavour and dry matter contents generally decrease (*Jorjani & Visser,* 1989; *Racskó* et al., 2004b). A too high nitrogen supply results in a considerable increase in fruit size, which can lead to a more intensive browning of skin and flesh, moreover, rotting of the core. However, numerous studies exist in which an opposite or no effect could be detected (*Goode & Higgs,* 1977; *Hipps* et al., 1990; *Johnson & Samuelson,* 1990; *Neilsen* et al., 1999). The differences in the results of the studies are primarily due to the different ecological and agrotechnical conditions.

Sass (1968) found in his experiments that one-sided nitrogen fertilization decreased the size and average mass of the fruits, the colouration, the average yield and total loss. Spotting, rotting and browning of the flesh were only increased slightly by extremely high dosages (1600 and 3200 kg N$\times$ha^{-1}) that are only of experimental importance.

Views on the relationship between nitrogen supply and storablility are not unanimous. Some scientists state that nitrogen overdosing has a negative effect only if the amount of potassium is too high compared to the calcium content at the same time (*Sharples,* 1968; *Fallahi* et al., 1997). However, *Schrader & Marth* (1930) found that nitrogen fertilization always has a negative effect on storability, but this is an indirect effect. This is manifested in a stronger canopy which has a greater shadowing effect resulting in a weaker colouration. On one hand, fruits with low colouration are prone to diseases and injuries of the skin, on the other hand, the disadvantageous effects of the latter are more definite during storage due to later harvesting. *Piskolczi* et al. (2003) and *Racskó* et al. (2004a) are of the same opinion, they claimed that infection by the fungi *Monilia fructicola* and *Venturia inaequalis* during storage has a negative effect on fruit quality and storability.

According to the studies of *Bünemann* (1958) nitrogen fertilization decreases the number of cells in the fruit, while it increases the size of the cells and cell size is inversely proportional with storability. Though the findings of *Bünemann* (1958) are supported by the results of *Racskó* (2004b), this aspect of the relationship between fruit quality and nitrogen supply is not frequently cited in the literature.

One-sided, high-dosage nitrogen and potassium fertilization decreases the pH value of soils with low buffering capacity such as sandy soils. This may result in calcium and magnesium deficiency, which causes a disharmony in nutrient supply and physiological and storage diseases will appear (*Atkinson* et al., 1980).

These differing views in the international literature call for a study on the relationships between nitrogen supply and fruit quality under the agroecological conditions of Hungary. The aim of the present study is to explore these relationships and to draw conclusions that can be incorporated into the practice.

Material and method

The experiments were carried out at Kálmánháza, Hungary in a private orchard in 2003–2004. The characteristics of the orchard and the studied cultivars are shown in *Table 1*. The row direction was N-S. Standard cultivation and integrated plant protection were applied on the experimental plots, no irrigation was performed.

Table 1 Characteristics of the orchard and the cultivars studied

Cultivar	Rootstock	Year of planting	Area (ha)	Plot size (m^2)	Distance between rows and within row (m×m)
Elstar	M4	1995	5.8	300	4.0×1.5
Gala Prince	MM106	1997	3.0	263	3.5×1.5
Granny Smith	MM106	1999	4.0	350	3.5×2.0
Idared	M4	1993	7.5	400	4.0×2.0

In order to study the effect of nutrient supply, nitrogen fertilization was applied. The dosage was divided into two applications, first 50 kg N$\times$ha^{-1} then an additional dosage (+50 kg N$\times$ ha^{-1} dosage in treatment C, +100 kg N$\times$ha^{-1} dosage in treatment D). When determining these dosages, we took into consideration that even besides these relatively low nitrogen doses the quality parameters of fruits can change measurably. The basic fertilization was performed in October with a solid, granulous fertilizer, while the second dosage was applied in May–June as a foliar fertilizer. The granulous fertilizer was mixed into the soil by using a disc cultivator. The data of fertilization are included in *Table 2*.

Table 2 Fertilization conditions (2003–2004)

Treatment	Nitrogen active ingredient (kg×ha^{-1})	Time of application			
		2003 Basic	2004 Foliar	2003 Basic	2004 Foliar
A	0	–	–	–	–
B	50	27 Oct	–	20 Oct	–
C	100	26 Oct	After 16 May	20 Oct	After 16 May
D	150	26 Oct	After 17 May	20 Oct May	After 18

In each treatment, assessments were made on 50 trees. Means of these data are included in the tables. Assessed trees were selected at the beginning of the experiment in five blocks per cultivars with ten trees in each block. For fruit assessments, 50 fruits were examined per cultivar.

The measured parameters were:

(1) *Fruit diameter:* It was measured by a vernier calliper with 0.1 mm punctutality by taking the mean of the largest and smallest diameter of the fruit.

(2) *Fruit height*: It was measured by using a vernier calliper with 0.1 mm punctuality along the greatest longitudinal circumference of the fruit.

(3) *Shape index*: It was calculated as a ratio of fruit height and fruit diameter. It was expressed with 0.001 precisity.

(4) *Fruit mass:* It was measured with a digital analytical scale with 0.1 g punctuality. Fruit mass is the mass of the washed fruit without fruit stalk.

(5) *Firmness*: It was measured with a Bishop hand penetrometer on the sunny and dark side of the fruit along the greatest cross-sectional diameter. It was expressed as a mean of the two values with 0.1 $kg \times cm^{-2}$ precisity.

(6) *Fruit colouration*: When examining colouration three categories were set up to ease visual assessment: 1. basic colour, 2. transition between basic and cover colour and 3. cover colour. The codes of the major colours representing these categories for each cultivar are shown in *Table 3*. We have determined coverage by the different colours using a transparent plastic sheet with mm scale. Cover by the different colours was expressed as a percentage of the total fruit surface using the following formula (*Nutter* et al., 1991; *Holb* et al., 2003):

Table 3 Codes of the colour sclae used for determining fruit colour of the studied apple cultivars*

Cultivar	Basic colour	Transition	Cover colour
Elstar	RAL 6018	RAL 1021	RAL 3020
Gala Prince	RAL 6018	RAL 2011	RAL 3018
Granny Smith	RAL 6010	RAL 1004	RAL 3014
Idared	RAL 6018	RAL 1028	RAL 3001

* Colours were determined using the RAL colour scale

$$cc = ca \times [\, 4\,\pi\, (fd/2)^2]^{-1} \times 100 \qquad (1.)$$

cc = degree of colour coverage (we assumed that each fruit is spherical; in this case the surface of the fruit is $4\,\pi\,(fd/2)^2$) [%]
ca = area covered by the different colurs [mm^2]
fd = fruit diameter [mm]

(7) *Canopy density*: It was graded on a linear scale from to 10. When determining canopy density, the length of shoots per unit canopy volume, the total number of branchings, the number of leaves and individual leaf area were taken into consideration (*Table 4*). These parameters were given a number on a scale from 1 to 10 based on their value and the mean of these four values gave the canopy density:

$$cd = (n_1 + n_2 + n_3 + n_4) \times 4^{-1} \qquad (2.)$$

cd = canopy density
n_1 = scale value of total shoot length
n_2 = scale value of the total number of branchings
n_3 = scale value of the total number of leaves
n_4 = scale value of individual leaf area

Results and discussion

The effect of nitrogen supply on the specific yields of apple

Many authors describe tree productivity as yield per tree (*Neilsen* et al., 1998; *Wrona*, 2004). However, for objective, temporal and spatial comparison, we suggest the use of specific yield. This measure is determined by two factors; the volume of the canopy and the yield of the tree.

In our experiments, these factors increased with increasing nitrogen dosages *(Figure 1)*. However, the increase in the vegetative surface was greater than the increase in the yield, therefore, specific yield decreased.

Results obtained in 2003 are shown in *Figure 1/A*. For all cultivars, the largest reduction (significant compared to the control) in specific yield was obtained when the highest nitrogen dose was applied. The dosage of 150 kg $N \times ha^{-1}$

Table 4 Parameters and their scale values used for determining canopy density

Total length of shoots (n_1)		Total number of branchings (n_2)		Total number of leaves (n_3)		Individual leaf area (n_4)	
m/m^3	Scale value	db/m^3	scale value	db/m^3	scale value	cm^2	scale value
≤=3.0	1	≤=30	1	≤=200	1	≤=5.0	1
3.1–6.0	2	31-60	2	201-400	2	5.1-10.0	2
6.1–9.0	3	61–90	3	401–600	3	10.1–20.0	3
9.1–12.0	4	91–120	4	601–800	4	20.1–30.0	4
12.1–15.0	5	121–150	5	801–1000	5	30.1–40.0	5
15.1–18.0	6	151–180	6	1001–1200	6	40.1–50.0	6
18.1–21.0	7	181–210	7	1201–1400	7	50.1–60.0	7
21.1–24.0	8	211–240	8	1401–1600	8	60.1–70.0	8
24.1–27.0	9	241–270	9	1601–1800	9	70.1–80.0	9
27.1=≤	10	271=≤	10	1801=≤	10	80.1=≤	10

greatly promoted shoot growth and consequently the volume of the canopy. This statement is also valid for cv. 'Elstar'; the highest value was obtained in the untreated control (7.29 kg×m^{-3}), while the lowest value was measured at the application of 150 kg N×ha^{-1} (6.50 kg×m^{-3}). In the case of cv. 'Gala Prince' there was no difference in the effect of 0 and 50 kg N×ha^{-1} on the specific yield, the measured value was 8.62 kg×m^{-3} for both. This value decreased with 0.17 kg×m^{-3} and 0.86 kg×m^{-3} besides a dosage of 100 kg and 150 kg N×ha^{-1}, respectively. The same trend was valid for cv. 'Granny Smith', however, the values were significantly lower due to the age of the tree and the charateristics of the MM 106 rootstock with a medium growth. The highest measured value in the case of the untreated control was only 5.59 kg×m^{-3}. In the order of increasing nitrogen dosages, the measured values were 5.52, 5.34 and 4.43 kg×m^{-3}, respectively. For cv. 'Idared', we could also measure a decrease in the specific yield, though no significant differences were found at the dosages of 0 and 50 kg N×ha^{-1}. A considerable decrease was detected only when 100 (0.51 kg×m^{-3}) and 150 kg N×ha^{-1} (1.02 kg×m^{-3}) were applied. The order of cultivars based on their specific yields was the same for all treatments: 'Granny Smith'<'Elstar'<'Idared'<'Gala Prince'. The standard deviations of the measure were high for cvs. 'Elstar', 'Gala Prince' and 'Granny Smith' especially when lower nitrogen dosages were applied.

Figure 1/B shows the calculated specific yield values for 2004. The measure decreased with increasing nitrogen supply in this year also. Among the studied cultivars, 'Elstar' and 'Granny Smith' were especially sensitive. For cv. 'Elstar', specific yield decreased proportionally with the increasing nitrogen dosages. Accordingly, the highest value was measured in the untreated control: 7.75 kg×m^{-3}. When applying 50, 100 és 150 kg N×ha^{-1} , the following values were obtained: 7.59, 7.20 and 6.54 kg×m^{-3}, respectively. In the case of cv. 'Gala Prince', the reduction was not so obvious, moreover, the application of the 50 kg N×ha^{-1} dosage resulted in a higher specific yield (8.60 kg×m^{-3}) than that of the control (8.51 kg×m^{-3}). Higher dosages significantly increased the size of the vegetative surface and the canopy, which caused a reduction of the calculated measure. In the case of cv. 'Granny Smith' having a low specific yield by nature, we also detected a significant decrease. The difference between the highest (6.35 kg×m^{-3}) and the lowest value (5.21 kg×m^{-3}) was 1.14 kg×m^{-3}. The yield value per unit canopy area were consderably higher than that for cv. 'Idared'. We measured 8.29 kg×m^{-3} in the control, which reduced to 7.62 when applying 150 kg N×ha^{-1}.

The effect of nitrogen supply on apple fruit quality

Besides yield description, fruit quality parameters are suitable for evaluating consumer preferences. Nitrogen supply affects these parameters mainly directly (fruit size, firmness and dry matter content), however, indirect effects can also be detected (colouration).

The impact of nitrogen supply on apple fruit diameter

The effects of different nitrogen dosages on apple fruit diameter in 2003 are shown in *Figure 2/A*. In general, it can

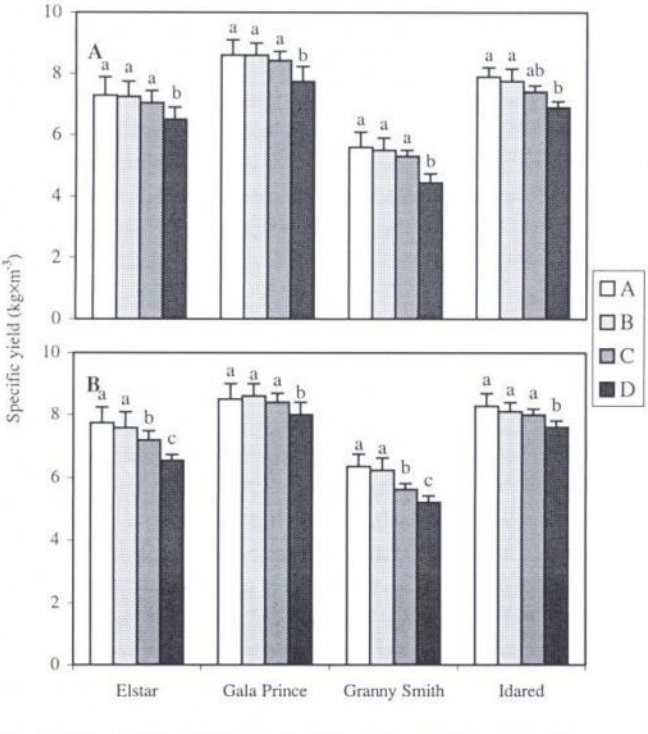

Figure 1 The effect of nitrogen supply on the specific yields of the apple cultivars studied in 2003 (A) and 2004 (B)

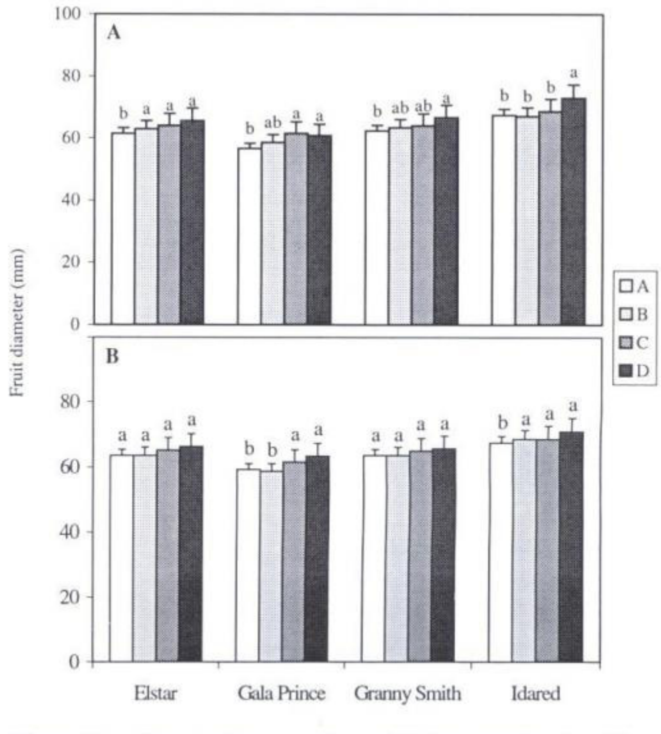

Figure 2 The effect of nitrogen supply on fruit diameter of apple cultivars in 2003 (A) and 2004 (B)

be stated that the diameter of the fruits increased with increasing nitrogen dosages. There was a definite increase in fruit diameter at all four cultivars, however, the effects of the dosages differed. Treatment "B" (50 kg N×ha^{-1}) increased the diameter at all cultivars compared to the control. The greatest increase was detected at cv. 'Granny Smith' (6.38%), then the cultivars in decreasing order were 'Idared' (5.26%), 'Elstar' (2.71%) and 'Gala Prince' (2.67%). For treatment "C" (100 kg N×ha^{-1}) the effect was not so obvious, moreover, in the case of cv. 'Idared' the 50 and 100 kg N×ha^{-1} dosages had the same effect, fruit diaemeter was 80.1 mm in both cases. On the contrary, treatment "D" (150 kg N×ha^{-1}) as compared to treatment "C" resulted in an increase in the fruit diameter at all four cultivars. This increment was the highest for cvs. 'Elstar' and 'Idared', with changes from 79.2 mm to 85.9 mm and from 80.1 mm to 87.0 mm, respectively. Such a considerable increase was not detected for cv. 'Granny Smith'. Nitrogen treatments and the consequent increases in fruit diameter increased the standard deviation of this measure too. Accordingly, the lowest deviation was measured in the control and the 50 kg N×ha^{-1} treatments, while the highest values were obtained in the 150 kg N×ha^{-1} treatment, no cultivar-specific treatments could be detected. Moreover, we observed that there was no change in the order of the cultivars compared to the control when ranked according to fruit diameter: 'Gala Prince'<'Granny Smith'<'Elstar'<'Idared'.

Figure 2/B shows the changes in the diameter in 2004. In this year, the cvs. 'Elstar', 'Gala Prince' and 'Idared' showed a favourable response to nutrient supply. For cv. 'Granny Smith', there was no significant increase in fruit diameter. As illustrated by the figure, the 50 kg N×ha^{-1} did not cause a significant change at any of the cultivars. Treatment "C" (100 kg N×ha^{-1}) had a stronger effect resulting in considerable differences compared to the control. This is well demonstrated by cvs. 'Elstar' and 'Gala Prince', at which diameter increased from 72.6 mm to 76.7 mm and from 68.4 mm to 73.3 mm, respectively. For cv. 'Granny Smith', there was no difference between treatments "B" and "C", the diameter was 71.2 mm in both cases. In the case of cv. 'Idared', only the 150 kg N×ha^{-1} dosage had a considerable effect, the diameter increased by 14.0 mm. A similary reaction was shown by cv. 'Elstar' with an increase of 10.4 mm resulting in a fruit diameter of 83.1 mm. A smaller change was detected at cvs. 'Gala Prince' and 'Granny Smith'. Treatment "D" resulted in only a 3.5 mm increase in fruit diameter for cv. 'Granny Smith'. The nitrogen dosages did not cause a significant change in the deviation of fruit diameter, in some cases the increasing nitrogen doses increased the standard deviation at a negligible extent. The original order of the cultivars ('Gala Prince'<'Granny Smith'<'Elstar'<'Idared') changed in the case of fruit diameter: 'Granny Smith'<'Gala Prince'<'Elstar'<'Idared'.

The effect of nitrogen supply on fruit height of apple cultivars

Figure 3/A shows the changes in fruit height caused by the different nitrogen dosages in 2003. We have found that similarly to fruit diameter, fruit height increased with increasing nitrogen supply. However, the increase was not as significant compared to the control as in the case of fruit diameter. Moreover, in some cases ('Gala Prince', 'Idared'), increasing nitrogen dosages decreased fruit height, though it was not significant. The 50 kg N×ha^{-1} dosage was effective for cvs. 'Elstar', 'Gala Prince' and 'Granny Smith'. The above-mentioned decrease in height (from 67.4 mm to 67.2 mm) at cv. 'Idared' was measured at this dosage. On the contrary, treatment "C" increased height in all cases compared to treatment "B". The highest increment was detected at cv. 'Gala Prince'; 4.94%. However, the fruit height of the same cultivar decreased at 150 kg N×ha^{-1} dosage (though the height increased compared to the control). In the case of the other cultivars, we measured an increase for treatment "D"; fruit height of cvs. 'Elstar', 'Granny Smith' and 'Idared' was 1.6 mm, 2.7 mm and 4.4 mm, respectively, compared to the 100 kg N×ha^{-1} dosage. Changes in the standard deviation values were not uniform. The order of the cultivars ranked according to fruit height did not change compared to the control: 'Gala Prince'<'Elstar'<'Granny Smith'<'Idared'.

The changes in fruit height of the four apple cultivars as a result of the nitrogen treatments in 2004 are represented in *Figure 3/B*. Treatment "B" (50 kg N×ha^{-1}) did not result in an obvious increase, since increment was detected only at cv.

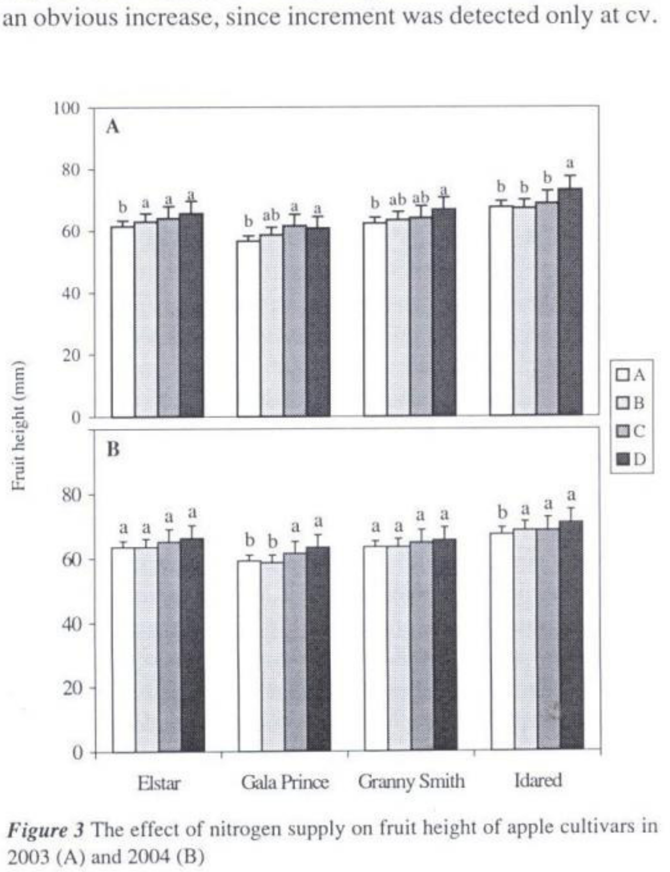

Figure 3 The effect of nitrogen supply on fruit height of apple cultivars in 2003 (A) and 2004 (B)

'Idared'. Fruit heights of cvs. 'Elstar' and 'Granny Smith' were similar to those of the control, while the fruit height of cv. 'Gala Prince' slightly decreased from 62.1 mm to 61.4 mm. Treatment "C" (100 kg N×ha^{-1}) had a more definite effect, since fruit height increased at all cultivars compared to the control. The highest increment of 1.6 mm was detected at cv. 'Elstar'. In the case of cv. 'Idared' treatment "B" had the same effect as treatment "C". The application of 150 kg N×ha^{-1} had an even greater effect. It increased fruit heigh at all cultivars compared to the control and treatment "C" in the order of: 'Granny Smith' (2.1 mm), 'Elstar' (2.8 mm), 'Idared' (3.5 mm) and 'Gala Prince' (4.1 mm). This modified the order of the cultivars from 'Gala Prince'<'Elstar'='Granny Smith'<'Idared' to 'Gala Prince'<'Granny Smith'<'Estar'<'Idared'. Changes in the deviation values were not uniform, the lowest value was detected in treatment "B".

The effect of nitrogen supply on fruit shape index of different apple cultivars

The author aimed to determine by the present study how nitrogen supply affects the shape of apple friuts. For describing the shape, the shape index was used. The value of this measure is determined by fruit diameter and fruit height.

Results are shown in *Table 5*. The trends of the table are not always obvious, however, it can be stated in general that the shape index decreased with increasing nitrogen dosages from the control to 150 kg N×ha^{-1}. This means that fruit diameter relatively increased compared to fruit height, that is fruits became slightly flattened. In 2003, shape index did not change for cv. 'Elstar' in the control and at 50 kg N×ha^{-1} dosage. The value of the measure slightly decreased at the dosage of 100 kg N×ha^{-1}, there was a considerable decrease of 0.065 in treatment "D" compared to the control. On the contrary, there was an increase from 0 to 100 kg N×ha^{-1} dosages for cv. 'Gala Prince', the shape index was reduced to a value lower than the control only at 150 kg N×ha^{-1}. For cv.'Granny Smith' the trend was the opposite, the shape index decreased in the order of treatments "A", "B" and "C", it increased slightly only at the 150 kg N¥ha^{-1} dosage. However, this was below the value of the control. In the case of cv. 'Idared', we measured a decrease in each nitrogen treatment compared to the control. The decrease, however, was not obvious, since treatment "C" slightly increased the shape index compared to treatment "B". The changes in the standard deviation of the shape index were not uniform, therefore no general conclusions could be drawn.

The changes of shape index in 2004 were similar to some extent to those of 2003, though it did not decrease uniformly in all cases. A gradual decrease was observed only for cvs. 'Elstar', 'Gala Prince' and 'Idared'. For cv. 'Elstar', the highest dosage (150 kg N×ha^{-1}) considerably decreased the shape index (by 0.076) compared to the control. A slight decrease was measured in treatments "B" and "C". For cv. 'Gala Prince', the decrease was smaller, but consequent (0.048). However, for cv. 'Granny Smith', shape index was decreased by the dosage of 50 kg N×ha^{-1} compared to the control, while at the dosage of 100 kg N×ha^{-1} an increase was detected. In treatment "D", the value of shape index decreased. For cv. 'Idared', an obvious decreasing trend was observed. The change in the standard deviation of the shape index was not uniform in 2004 either, though a slight decrease could be detected at some cultivars.

Table 5 The effect of treatments on the fruit shape index of apple cultivars

Year	Cultivar	Treatment "A"	Treatment "B"	Treatment "C"	Treatment "D"
2003.	Elstar	0.829±0.024	0.829±0.019	0.808±0.025	0.764±0.029
	Gala Prince	0.842±0.016	0.849±0.015	0.883±0.020	0.816±0.017
	Granny Smith	0.885±0.034	0.847±0.029	0.830±0.031	0.854±0.032
	Idared	0.887±0.035	0.840±0.035	0.858±0.280	0.839±0.043
2004.	Elstar	0.875±0.022	0.866±0.023	0.849±0.021	0.799±0.027
	Gala Prince	0.867±0.011	0.849±0.009	0.840±0.012	0.819±0.011
	Granny Smith	0.900±0.019	0.892±0.031	0.912±0.028	0.886±0.028
	Idared	0.887±0.043	0.886±0.034	0.858±0.045	0.788±0.049

The effect of nitrogen supply on the fruit mass of apple cultivars

Besides fruit diameter and fruit height, fruit mass is used describing fruit size. Changes in fruit mass resulting from nitrogen fertilization are shown in *Figure 4*. Increasing nitrogen dosages resulted in similar changes as at the previous two characters. In 2003, the most obvious increase in fruit mass was observed in cvs. 'Elstar' and 'Idared' *(Figure 4/A)*. For cv. 'Elstar', the increase was proportional with the applied nutrient dosage. Treatment "B" resulted in the highest mass increment at this cultivar with 6.1 g. The order of the other cultivars was 'Granny Smith' (5.0 g), 'Gala Prince' (3.1 g) and 'Idared' (3.0 g). Treatment "C" did not cause an increase in fruit mass in all cases. This statement is valid for cv. 'Granny Smith', since its fruit mass was the same at the dosages 50 and 100 kg N×ha^{-1} (161.2 g). High positive differences in fruit mass were not observed at the other three cultivars either. However, the 150 kg N×ha^{-1} dosage had a significant effect on all four cultivars. The greatest increase compared to the control was observed in cv. 'Idared' (15.17%), followed by 'Elstar' (14.12%), 'Granny Smith' (7.69%) and 'Gala Prince' (5.77%). The standard deviation increased generally with increasing nitrogen dosages and fruit mass. There was no change in the order of cultivars as compared to the control ('Gala Prince'<'Granny Smith'<'Elstar'<'Idared') at the highest applied dosage. .

Figure 4/B represents the changes of fruit mass in 2004. Similarly to the results of 2003, there was an increase in fruit mass. The application of 50 kg N×ha^{-1} did not result in a significant change at the four cultivars, moreover, fruit mass was the same as in the control for cv. 'Granny Smith'(157.1 g). In treatment "C", cv. 'Elstar' showed a strong response, its fruit mass increased by 10.80 g compared to the control. It was followed by cv. 'Idared' with 5.20 g, 'Gala Prince'

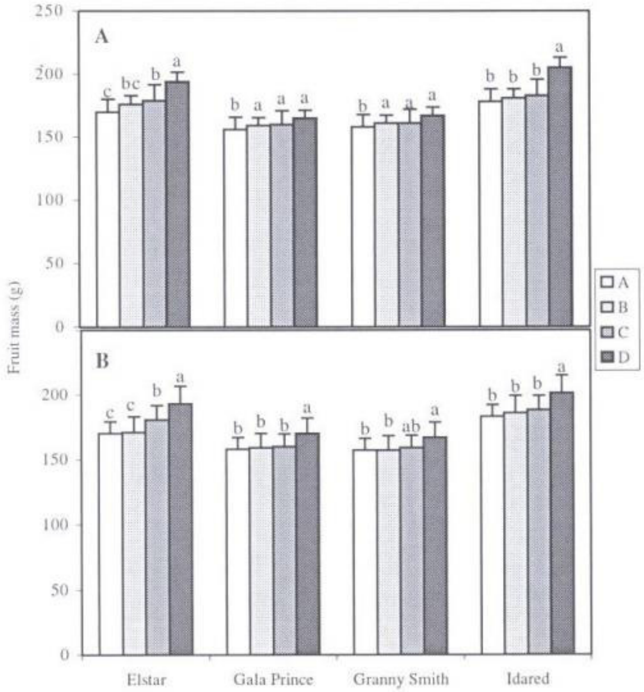

Figure 4 The effect of nitrogen supply on fruit mass of apple cultivars in 2003 (A) and 2004 (B)

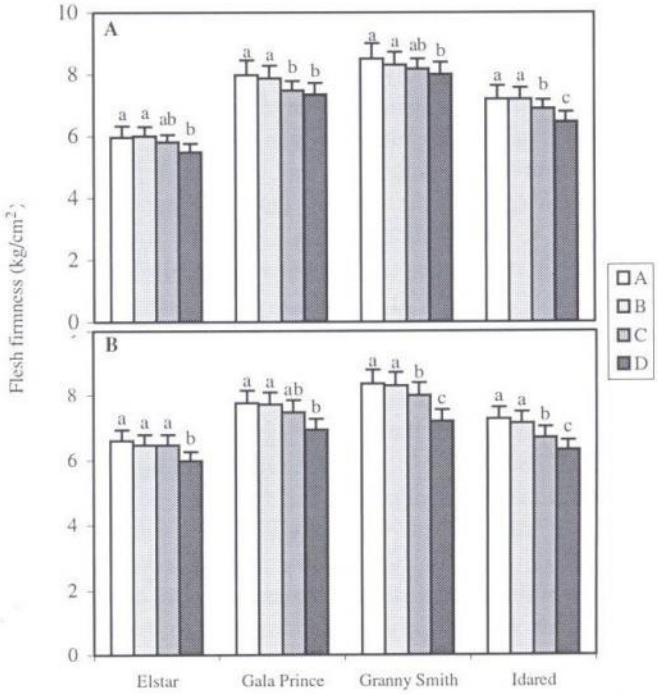

Figure 5 The effect of nitrogen supply on the flesh firmness of apple cultivars in 2003 (A) and 2004 (B)

and 'Granny Smith' with 2.1 g both. Only the application of 150 kg N×ha^{-1} resulted in a considerable change at all cultivars: the increase in cv. 'Idared', 'Elstar', 'Gala Prince' and 'Granny Smith' was 6.91, 6.75, 6.24 and 5.03%, respectively, compared to treatment "C". The standard deviation of fruit mass increased with increasing nitrogen dosages in 2004 also. The relative order of cultivars in the control was: 'Granny Smith'<'Gala Prince'<'Elstar'<'Idared'. While the order was the same as in 2003 when 150 kg N×ha^{-1} was applied ('Gala Prince'<'Granny Smith'<'Elstar'<'Idared').

The effect of nitrogen supply on the flesh firmness of apple

Opposite to the positive changes in the above fruit quality parameters, firmness was characterized by a decreasing trend with increasing nitrogen dosages. The application of 50 kg N×ha^{-1} did not result in an obvious reduction of firmness compared to the control in 2003, since for cv. 'Elstar', it increased from 5.96 kg×cm^{-2} to 6.01 kg×cm^{-2}, while for cv. 'Idared', the value was the same for both dosages, 7.20 kg/cm^{-2} (Figure *5/A*). At this dosage only cvs. 'Gala Prince' and 'Granny Smith' showed a slight decrease of firmness with 0.09 and 0.18 kg×cm^{-2}, respectively. A decrease in firmness could be detected in treatment "C" compared to the control and treatment "B". A similar trend was observed for treatment "D". The highest reduction compared to the control was measured in cv. 'Idared' from 7.20 to 6.45 kg×cm^{-2}. No obvious trend was observed for the standard deviation, its value was ±7–8% for all four cultivars. The relative order of cultivars for firmness did not change as compared to the control: 'Elstar'<'Idared'<'Gala Prince'<'Granny Smith'.

Figure 5/B shows the firmness values measured in 2004. The trend was similar to that of 2003; the application of 50 kg N×ha^{-1} did not result in a considerable change of firmness. However, the change caused by the highest dosage (150 kg N×ha^{-1}) was more significant. For cv. 'Elstar', treatments "B" and "C" produced the same firmness value (6.47 kg×cm^{-2}). For the other three cultivars, a reduction could be observed in both treatments compared to the control. Reduction in firmness compared to the control (7.27 kg×cm^{-2}) was the greatest at cv. 'Idared' with 0.56 kg×cm^{-2}. Higher reductions than that were only observed when 150 kg N×ha^{-1} was applied. The order of reductions was: 'Granny Smith' (1.17 kg×cm^{-2}), 'Idared' (0.96 kg×cm^{-2}), 'Gala Prince' (0.84 kg×cm^{-2}) and 'Elstar' (0.63 kg×cm^{-2}). The standard deviation decreased with increasing nitrogen dosages especially for cvs. 'Elstar' and 'Idared'

The effect of nitrogen supply on dry matter content of apple cultivars

Figure 6 shows the changes in dry matter content as a result of the different nitrogen dosages. In most of the cases the observed cultivars reacted negatively to the increasing nitrogen dosages: at higher dosages lower dry matter contents were measured. This statement is supported by *Figure 6/A*, which shows the results of 2003. A significant decrease in the dry matter content was measured (0.6 ref%) compared to the control (16.1 ref%) when 50 kg N×ha^{-1} was applied at cv. 'Elstar'. At a dosage of 100 kg N×ha^{-1}, a slight increase was observed (0.2 ref%), while at the 150 kg N×ha^{-1} dosage a decrease followed again (0.9 ref%). A similar decreasing trend was also detected at cv. 'Gala Prince'.

A small, not significant increase in dry matter content was observed at a dosage of 50 kg N×ha^{-1}. The increasing nitrogen dosage gradually decreased the dry matter content, with the lowest value being measured at N×ha^{-1} (15.1 ref%). An obvious negative relationship could only be proven at cv. 'Granny Smith'. The decrease was more definite at higher nitrogen dosages. In the control, the value decreased from 16.1 ref% to 15.2 ref%. For cv. 'Idared', there was no difference in dry matter content between the control and the 50 kg N×ha^{-1} dosage, it was 15.8 ref% in both cases. A reduction in dry matter content was caused only by the higher dosages of 100 and 150 kg×ha^{-1} with 0.4 and 0.7 ref%, respectively. The cultivars differed in their responses to nitrogen supply, since the order of cultivars measured in the control ('Gala Prince'<'Idared'<'Granny Smith'<'Elstar') has changed at the application of the highest dosage ('Gala Prince'='Idared'<'Elstar'<'Granny Smith').

In 2004, slightly higher dry matter contents were measured and the decrease was lower in several cases than in the previous year *(Figure 6/B)*. Compared to the 16.3 ref% value of the control, we measured 0.3, 0.4 and 0.4 ref% in cv. 'Elstar' when 50, 100 and 150 kg N×ha^{-1} dosages were applied, respectively. A decrease in the dry matter content of cv. 'Gala Prince'was also observed in parallel with the increase of nitrogen supply, however, this negative change was smaller when 150 kg N×ha^{-1} was applied (0.2 ref%) than at the 100 kg N×ha^{-1} dosage (0.3 ref%). On the contrary, an opposite change was detected at cv. 'Granny Smith': at 0 and 50 kg N×ha^{-1} dosages 16.1, while at 100 and 150 kg N×ha^{-1} dosages 16.2 ref% were measured. In this case, the change in the dry matter content of fruits was proportional with the nitrogen dosages. For cv. Idared, the relazionship was not obvious, since dry matter content

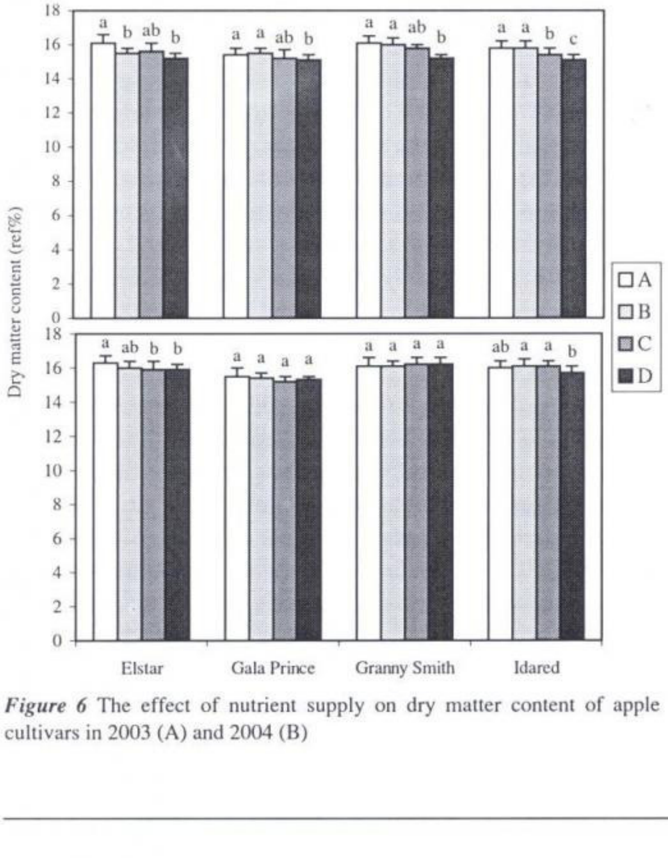

Figure 6 The effect of nutrient supply on dry matter content of apple cultivars in 2003 (A) and 2004 (B)

increased by 0.1 ref% when 50 and 100 kg N×ha^{-1} was applied and it decreased to 15.7 ref% only at the dosage of 150 kg N×ha^{-1} compared to the control value of 16.0 ref%.

The effect of nitrogen supply on canopy density of apple trees

In our opinion nitrogen supply has an indirect effect on the fruit quality of apple via affecting the morphology of the tree, since the applied the nitrogen increases the vegetative production of the tree considerably. Due to this change, the amount of light necessary for the colouration of the fruits significantly decreases, and the colour coverage remains low. This casues a reduction in the quality of red coloured cultivars ('Elstar', 'Gala Prince', 'Idared'), while the same effect is preferred by the consumers at cultivars without a cover colour ('Granny Smith').

In *Figure 7*, the changes in the canopy density resulting from the different nitrogen dosages are presented. In the experiment, the increasing macroelement supply was accompanied by an increase in the canopy density. In 2003, canopy density of all the apple cultivars correlated positively with the applied nitrogen fertilizer dosages *(Figure 7/A)*. For all cultovars, a considerable increase in the canopy density was detected only when 100 and 150 kg N×ha^{-1} dosages were applied. For cv. Elstar, the dosages 50, 100 és 150 kg N×ha^{-1} dosages resulted in values of 7.55, 8.23 and 8.32, respectively, compared to 7.41 in the control treatment. A similar trend was observed for cv. 'Gala Prince', but the values were lower due to the lower canopy density that is a characteristic of the cultivar. The highest dosage increased the controll value of 6.5 by 1.30. For cv. 'Granny Smith' the increase was not so definite, since the nitrogen dosages increased the controll density of 8.69 by 0.07, 0.52 and 0.76, respectively. For cv. 'Idared', a significant increase was also detected at the dosages of 100 and 150 kg N×ha^{-1}, the increase in density was 1.16 and 1.61, respectively, compared to the control. The changes in density due to fertilization were of the same degree since the order of cultivars ('Gala Prince'<'Elstar'<'Idared'<'Granny Smith') was not altered even at the highest dosage. Changes in the standard deviation did not lead to a soild conclusion, we observed that in the control with the lowest canopy density, the deviations were frequently high.

In 2004, the results were similar to those of 2003, but the increase in the canopy density was not so obvious *(Figure 7/B)*. The higher nitrogen dosages did not result in a higher canopy density in all cases (e.g. 'Granny Smith'). For cv. 'Elstar', the nitrogen dosages of 50 and 100 (and 150) kg N×ha^{-1} resulted in a statistically significant difference, the values were 8.00 and 8.44 compared to the control (7.52). For cv. 'Gala Prince', the change in the canopy density was proportional with the applied fertilizer dosage, the increments in the different treatment were similar. However, a slight (not significant) decrease of 0.10 was detected for cv. 'Granny Smith' at the application of 50 kg N×ha^{-1} compared to the control. However, dosages higher than that

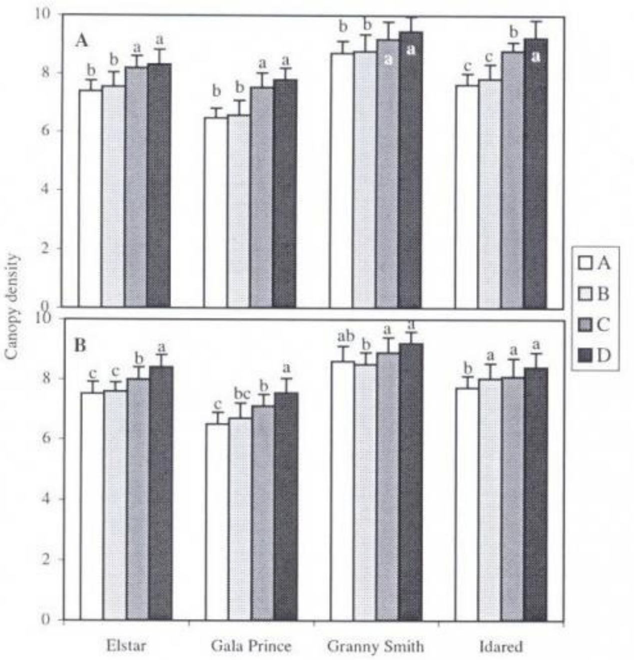

Figure 7 The impact of nitrogen supply on the canopy density of apple cultivars in 2003 (A) and 2004 (B)

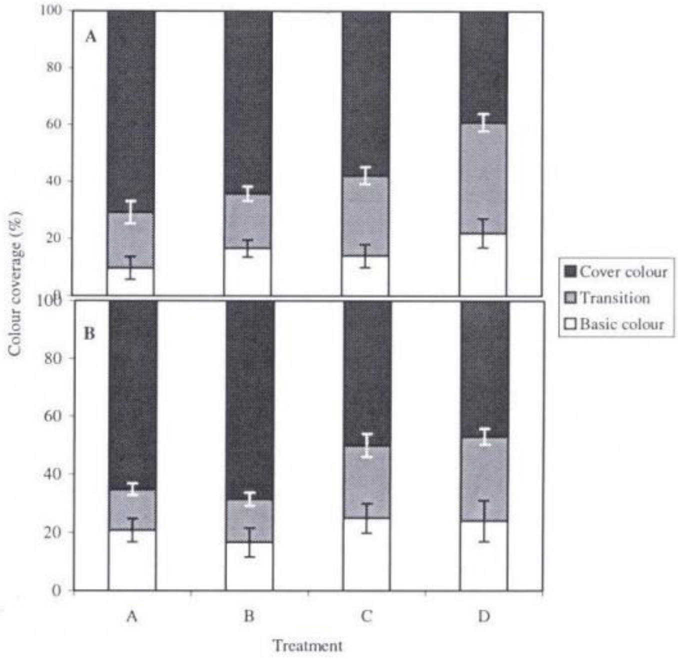

Figure 8 The effect of nitrogen supply on colouration of cv. Elstar in 2003 (A) and 2004 (B)

increased the originally high canopy density of cv. 'Granny Smith' until reaching 9.20. No decrease was observed at cv. 'Idared', the canopy density increased with increasing nitrogen dosages. The lowest (7.72) and highest (8.41) values were measured in the control and the 150 kg N×ha^{-1} treatments, respectively. In 2004, the order of the cultivars according to their canopy density was: 'Gala Prince'<'Elstar'<'Idared'<'Granny Smith', so the nitrogen supply changed the place of 'Elstar' and 'Idared'.

The impact of nitrogen supply on the colouration of apples

Figures 8–11 demonstrate the changes in the colour coverage proportions of the fruits. The increasing nitrogen dosages decreased the colouration of the fruits due to the increased shadowing effect of the vegetative parts. For three of the four studied cultivars ('Elstar', 'Gala Prince', 'Idared') good colouration is an important quality requirement, while for cv.'Granny Smith' the high proportion of the basic colour, low colouration is the criterion for marketability. The low proportion and reduction of the transitional colouration is an important requirement for all cultivars. A change in the proportion of the three colour groups results in an opposite change in the proportions of the other two groups.

Increasing nitrogen dosages resulted in a decreased colouration of cv. 'Elstar' both in 2003 and 2004 *(Figure 8)*. The reduction was due to the increase in the basic and the transitional colouration resulting from the reduced light supply of the fruits. In 2003, a basic colouration of 9.7% was measrued, which gradually increased to 22.1% after a slight decrease at 150 kg N×ha^{-1} dosage *(Figure 8/A)*. An increasing trend in the transitional colouration could be observed. Starting from 19.5% in the control, the transitional colouration increased to 39.2% at the 150 kg N×ha^{-1} dosage. Simultaneously, the cover colouration decreased. It decreased gradually, the reduction was proportional to the applied dosage. When no nitrogen was applied 70.8% of the fruits' surface was red. This proportion decreased considerably at the 150 kg N×ha^{-1} dosage by 31.3% to 39.5%. No trend was observed in the standard deviations of colouration.

In 204, the obtained results were similar to those above *(Figure 8/B)*. Though the increase in the basic colouration was not as large as in 2003, the same trend was observed. A slight decrease of 4.2% was measured when applying 50 kg N×ha^{-1} in 2004, compared to the control. At the dosages of 100 kg N×ha^{-1} and 150 kg N×ha^{-1}, the basic colouration was 24.9% and 24.0%, respectively. The standard deviations were greater than in 2003. A continuous increase was registered in the transitional colouration, but it was not proportional with the applied dosages. This type of colouration was especially high at the dosages of 100 and 150 kg N×ha^{-1} with 25.7 and 29.4%, respectively. An opposite trend was detected for the cover colouration, meaning that a 3.4% increase was measured compared to control when 50 kg N×ha^{-1} was applied, that is the cover colouration was 68.6%. Higher dosages than that decreased the value to 50.1 and 47.3% at 100 and 150 kg N×ha^{-1}, respectively. No trend was observed in the standard deviations of the colouration in 2004 either.

Figure 9 represents the changes in the three types of colouration as a result of the nitrogen supply for cv. 'Gala Prince'. In 2003, the basic colouration was very low 1.5% for the control (Figure 9/A). The increasing nitrogen dosages resulted in a gradual increase of this colouration. At 150 kg N×ha^{-1} dosage, 28.4 % was measured. The change in the transitional colouration was the opposite, the highest value

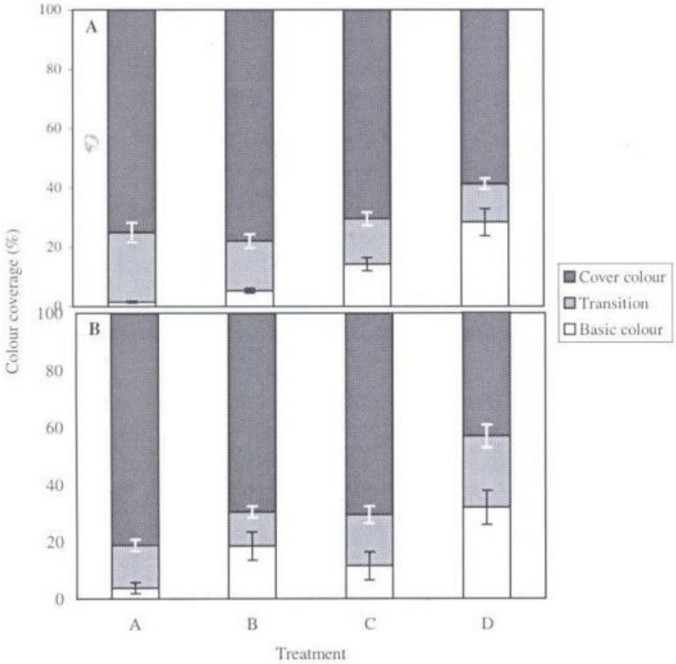

Figure 9 The effect of nitrogen supply on fruit colouration of cv. Gala Prince in 2003 (A) and 2004 (B)

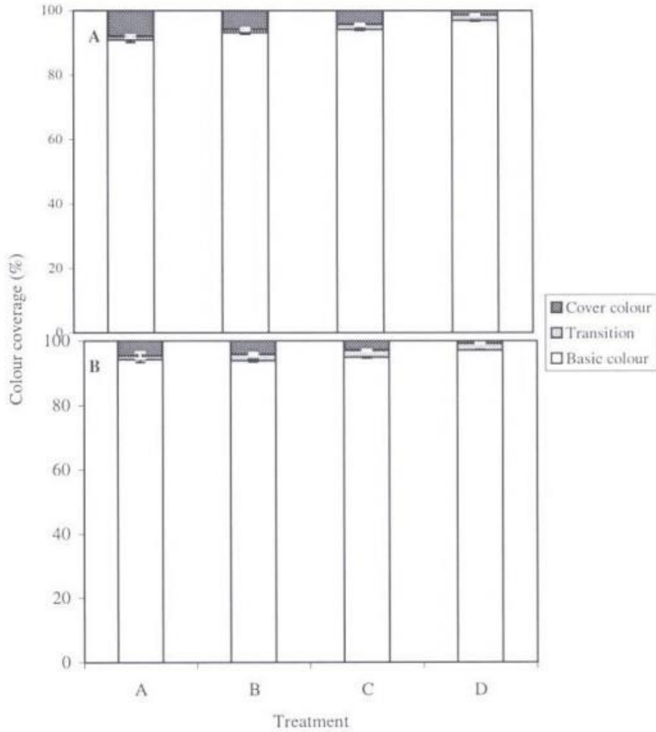

Figure10 The effect of nitrogen suply on fruit colouration of cv. Granny Smith in 2003 (A) and 2004 (B)

was measured in the control (23.5%), while the lowest was detected at the 150 kg N×ha^{-1} dosage (12.9%). It decreased gradually with the increasing nitrogen dosages. This statement was not valid for the cover colouration. The highest proportion of cover colouration was observed for cv. Gala Prince among the studied cultivars. Though a decrease was observed, it was not as obvious as for the transitional colouration, since the control value of 75.0% increased to 77.9% in the 50 kg N×ha^{-1} treatment. Compared to the control, the dosages of 100 and 150 kg N×ha^{-1} resulted in a 4.6 and 16.3% decrease, respectively. The standard deviation of the coluration measures changed in proportion with the ratio of the different colours.

In *Figure 9/B*, the changes in the proportions of the different colurations are shown for 2004. In sum, the basic colouration was increasing, but there was a break in the trend at 100 kg N×ha^{-1} dosage, since the increment due to the 50 kg N×ha^{-1} dosage was 14.7%, while at the 100 kg N×ha^{-1} dózosage it was only 10.7%. The highest basic coluration of 32.2% was measured at the 150 kg N×ha^{-1} dosage. With increasing dosages, the transitional colouration also increased, though the lowest value (12.4%) was measured in the 50 kg N˜ha^{-1} treatment and not in the control. This was followed by the values of 15.0, 18.7 and 25.3% for the 0, 100 and 150 kg N×ha^{-1} dosages, respectively. The decrease in the cover colouration was the greatest for this cultivar, at the application of 150 kg N×ha^{-1} only 43.1% was measured compared to the control value of 81.2%. This resulted in a significant decrease in the fruit quality. The low standard deviations also supported this, which prove that the individual values were vey close to the average. Not even a small portion of the fruits satisfied the consumer preferences of high cover colouration.

The quality requirements of the consumers are totally different from the above for cv.'Granny Smith' as regards colouration. It is well-known, that the appearance of a red-pink colouration is disadvantageous. However, this cannot be prevented in the intensive orchards with high plant density due to the growing site, the cultivar structure and the form of the crown.

In 2003 and 2004, the proportion of the green colouration representing a high quality was gradually increased by the increasing nitrogen *(Figure 10)*. Accordingly, the lowest (91.1%), and the highest (96.9%) values were measured in the control and the 150 kg N×ha^{-1} treatment, respectively, in 2003 (Figure *10/A*). A similar trend was observed for the transitional colouration, though we measured the same value (1%) in the control and the 50 kg N×ha^{-1} treatment. On the contrary, the cover colouration was decreasing. The highest and lowest values were 8.2% (0 kg N×ha^{-1}) and 1.3% (150 kg N×ha^{-1}), respectively. The standard deviations of the different colour groups changed in proportion with the ratio of the colour cover.

The results of 2004 were similar to those of the previous year *(Figure 10/B)*. The ratio of the basic colouration was higher in 2004 than in 2003. Compared to the control (94.3 %), the value decreased by 0.4% and then increased by 0.6 and 2.8% for the treatments 50, 100 and 150 kg N×ha^{-1}, respectively. The transitional colouration was negligible in this year also with a maximum of 2.1% in the treatments of 100 and 150 kg N×ha^{-1}. The cover colouration decreased considerably at the dosages of 100 and 150 kg N×ha^{-1} to 3.0 and 0.8%, respectively. This latter value is practically negligible. The standard deviations were not significant due to the small percentage values.

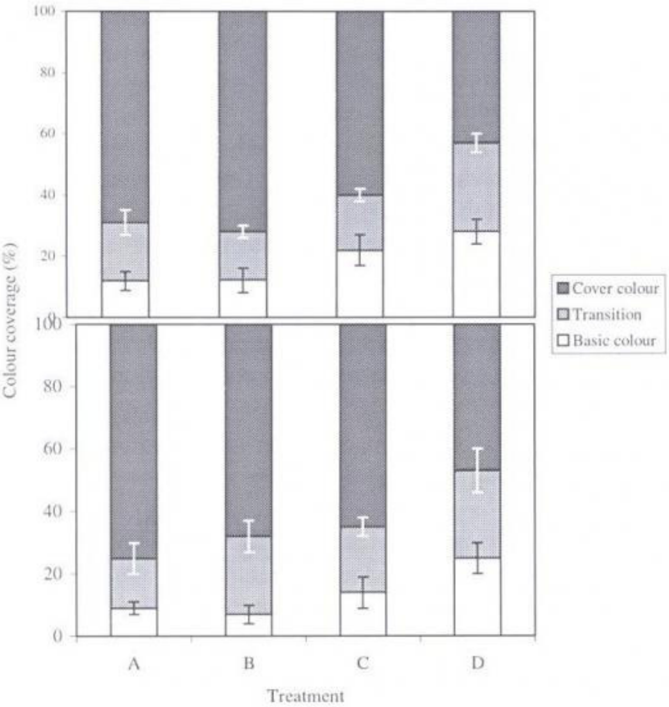

Figure 11 The effect of the nitrogen supply on fruit colouration of cv. Idared in 2003 (A) and 2004 (B)

Though the cover colouration was very low in both years, it was very striking due to the high contrast. Therefore, even these low values cannot be neglected, especially not in the control. This disadvantegous effect was mitigated by the increasing nitrogen dosages (due to their positive effect on the habit of the canopy) via decreasing the red-pink colouration). The application of higher nitrogen dosages increased the favourable green colouration in cv. 'Granny Smith', via this effect (and the increase in the fruit size) it virtually improved fruit quality. However, disregarding of the further effects of this nutrient can involve grave consequences:

- increasing nitrogen dosages considerably decrease the originally small thickness of the fruit's epidermis, which results in an increased sensitivity of thre fruits to mechanical injury bot in the field and during storage and opens an entrance for the pathogens and pests;
- another disadvantegous effect of the high nirtogen dosages is the decrease in the number of fruit cells and the increase in the cell size, which hinder the long-term storability of the fruits;
- In parallel with this, the dry matter content that determines taste decreases slightly with the increasinh nitrogen dosages.

Figure 11 represents the changes in the coluration of cv. 'Idared'. In 2003, the basic colouration increased similarly to the other cultivars *(Figure 11/A)*. The increase was continuous. The difference between the control and the 50 kg N×ha^{-1} treatment was minimal, the latter was 0.2% higher. The maximum value of 28.7% was measured in the 150 kg N×ha^{-1} treatment. The transitional colouration was high compared to that of cv. 'Granny Smith'. For this parameter, no obvious trend in the nutrient response could be detected, since the lowest value (15.8%) measured in the 50 kg N×ha^{-1} treatment was followed by 18.2% and 19.3% in the 100 kg N×ha^{-1} treatment and in the control, respectively. The highest transitional colouration (29.6%) was measured when 150 kg N×ha^{-1} was applied. For the cover colouration the direction of the change was more obvious, it decreased with increasing nitrogen dosages. The decrease of 2.8% in the 50 kg N×ha^{-1} treatment as compared to the control did not break the trend. The lowest value (43.5%) was observed in the 150 kg N×ha^{-1} treatment.

In 2004, the increase in the basic colouration was not as great as in 2003, however, the same trend could be observed *(Figure 11/B)*. In 2004, a small reduction of 2.0% was measured in the 50 kg N×ha^{-1} treatment compared to the control (9.1%). At the dosages of 100 kg N×ha^{-1} and 150 kg N×ha^{-1} , a basic colouration of 14.7%, and 25.4% was measured, respectively. The standard deviations increased mostly in parallel with the figures. The changes in the transitional coluration were not consequent in this year either, though the lowest value (16.3%) was measured in the control, while the highest value was detected in the 150 kg N×ha^{-1} treatment (28.5%). Similarly to the above cultivars, the cover colouration decreased with the increasing nutrient supply for this cultivar also: from 75.1 %-ról (0 kg N×ha^{-1}) to 47.4%-ra (150 kg N×ha^{-1}).

Relationships between canopy density and some fruit quality parameters

In our experiments, we studied the relationships between canopy density and fruit quality, because the amount and the quality of the assimilation products are determined primarily by the vegetative canopy. An obvious effect is that the density of the canopy influences the amount of light reaching the fruits and via this the colouration, firmness and dry matter content of the fruits. This verifies the study of the relationship between nitrogen supply and fruit quality.

We studied the relationships between the canopy density and some fruit quality parameters (fruit mass, firmness, dry matter content, cover colouration). The results are presented in *Figures 12–15*.

The relationship between canopy density and fruit mass

The relationship between canopy density and fruit mas could be described the best by a quadratic polynomial function for three of the four studied cultivars *(Figure 12)*. The function is convex and has a maximal fruit mass value. The highest individual fruit mass is usually detected at a canopy density value lower than the maximum. The correlation coefficient is cultivar-specific, the highest value was detected at cv. 'Elstar' at a canopy density of 8.0–8.2. The shape of the function was similar in both years for this cultivar. The curve was more depressed for cv. 'Gala Prince' than for cv. 'Elstar', meaning that the fruit mass does not respond so sensitively to the change of the canopy density.

The highest fruit mass was obtained at the canopy density of 7.43 and 7.26 in 2003 and 2004, respectively. The characteristics of the function were also similar in both years, however, the standard deviation of the fruit mass was higher in 2004. On the contrary, for cv. Granny Smith the relationship between the two factors was rather linear. (The correlation coefficient for the linear approach was higher than that of the quadratic polynomial function). For cv. 'Idared' a trend-line with one peak can be observed with a maximal canopy density of 8.48 in and 7.35 in 2004.

The relationship between canopy density and flesh firmness

Figure 13 represents the relationship between canopy density and firmness. The relationship was described by a negative linear function. Accordingly, a higher canopy density was accompanied by a lower firmness value (except for 'Granny Smith' in 2004). The most sensitive among the cultivars was 'Gala Prince', the steepness of the linear function was the highest for this cultivar. In 2003, the relationship was obvious for cvs. 'Elstar' and 'Idared'. The trend was also decreasing with increasing canopy density in 2004. In 2003, no significant difference was observed in

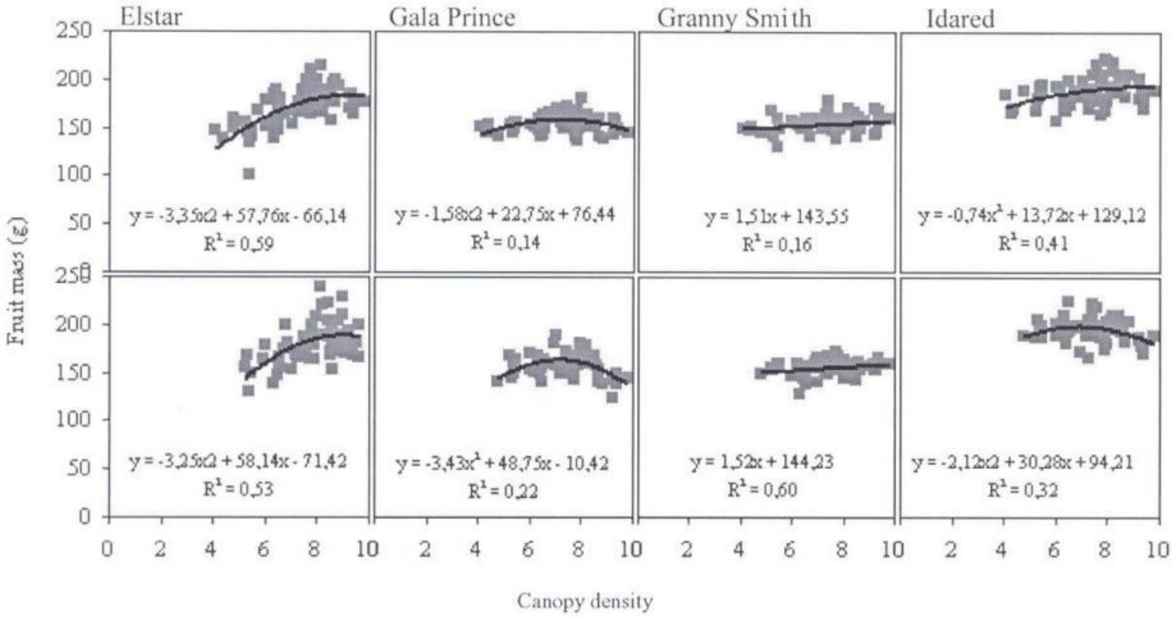

Figure 12 The relationship between canopy density and fruit mass

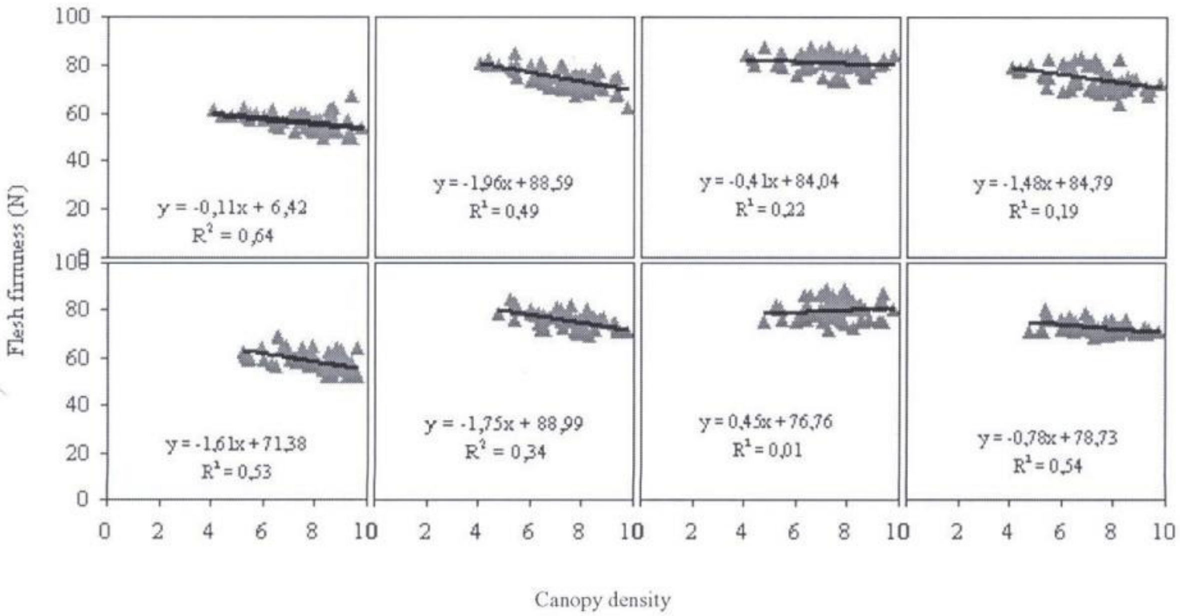

Figure 13 The relationship between canopy density and flesh firmness of the fruits

firmness at different canopy densities for cv. 'Granny Smith', moreover, the two measures increased in parallel with each other in 2004.

The relationship between canopy density and dry matter content

Figure 14 shows the relationship between canopy density and dry matter content of fruits. This relationship could be best describes by a linear, negative function in most cases. The steepness of the curve shows what effect has a unit change in the canopy density on the dry matter content of fruits. It can be stated that at a higher canopy density results in a lower dry matter content in most of the cases. This seems to contradict the assumption that a higher canopy density with a larger assimilation surface could provide the fruits with more assimilates and thereby increase their dry matter content. However, it is not that simple. Since a higher canopy density means also a higher number of branches and twigs. The assimilate requirements of the growth of woody parts are considerably higher than those of the fruits, therefore the woody parts compete with the reproductive parts and decrease their dry matter content. A more dense canopy also decreases the amount of light reaching the fruits, which also contributes to the lower dry matter content.

The positive change in the canopy density resulted in the largest reduction in dry matter content at cvs. 'Gala Prince' and 'Elstar' in 2003 and 2004, respectively. Cvs. 'Granny Smith' and 'Idared' were also sensitive to this effect. In 2004, the negative linear relationship was not so strong for the studied cultivars, moreover, a positive relationship was detected at cv. 'Granny Smith', while for cv. 'Idared' a quadratic polynomial relationship was found.

The relationship between canopy density and colour coverage

The relationship between canopy density and cover colouration of the fruits is shown in Figure *15*. The functions are linear and of negative sign for all cultivars similarly to those for firmness and dry matter content. The steepness is the highest for this measure, so the canopy density has the strongest effect on the cover colouration. This is due to the fact, that a precondition of cover colouration is the direct solar radiation. This cannot be provided in a more dense canopy, which considerably decreases colouration. This is a disadvantageous quality for cvs. 'Elstar', 'Gala Prince' and 'Idared', however, it is favourable for cv. 'Granny Smith', since consumers prefer the dark-green fruits without a cover colouration in the case of this cultivar. Therefore, a higher canopy density can be advantageous for this fruit quality parameter (however, for the complex evaluation of the product value, fruit size, firmness and dry matter content should also be considered).

No significant difference was detected between the two years for any cultivar. The most sensitive cultivar was 'Elstar'. This is proven by the high correlation coefficient of the linear trend in 2004. A unit change in the canopy density resulted in a greater change in the cover colouration of cv. 'Elstar' in 2004 than in 2003. A similar trend was observed for cv. ' Gala Prince'. In this case, there was no considerable difference in the shape of the curves between the years. The tightness of the correlations is demonstrated by the correlation coefficients: R^2=0.73 in 2003, R^2=0.62 in 2004. On the contrary, the sensitivity of cv. 'Granny Smith' was very low. This was due to the low colouration and the high standard deviations. For. cv. 'Idared', a considerable decrease was detected in the cover colouration with increasing canopy density. This statement was valid for both experimental years.

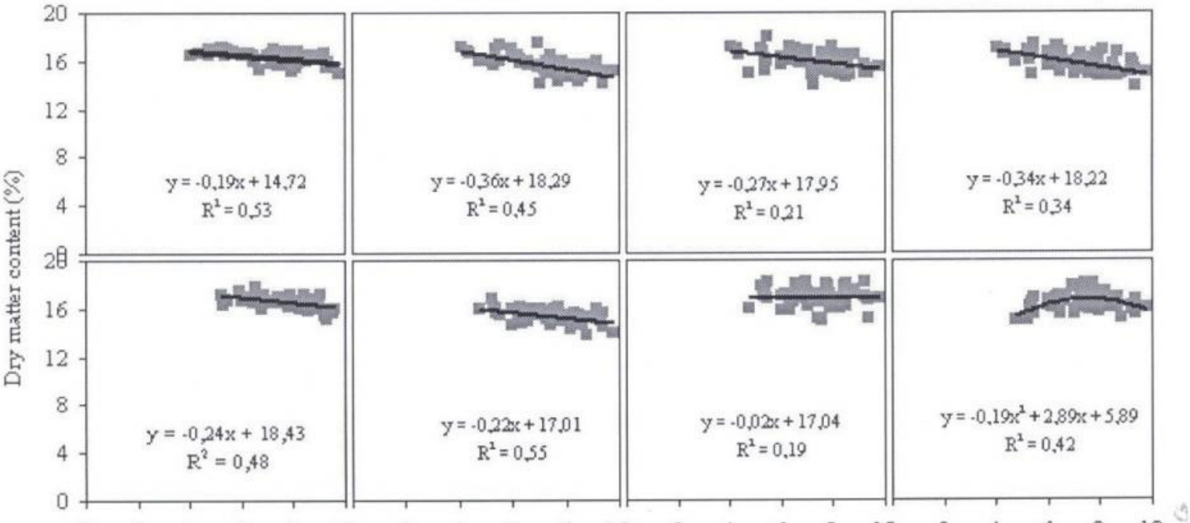

Figure 14 The relationship between canopy density and dry matter content

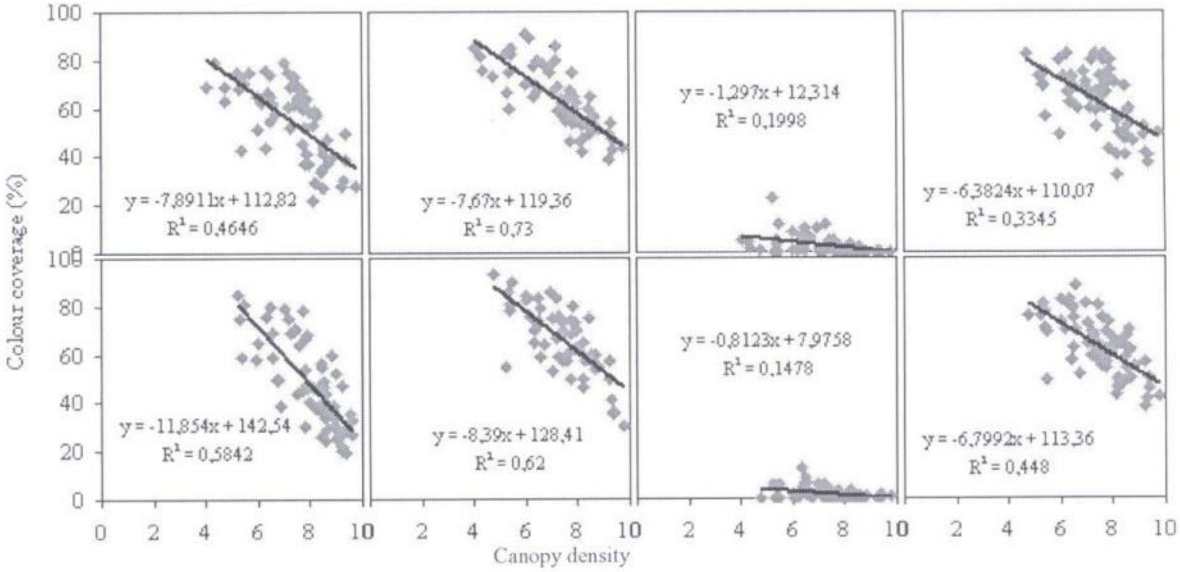

Figure 15 The relationship between canopy density and cover colouration

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