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QUALITY OF INTENSIVELY PRODUCED CROPS

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INTRODUCTION

Farmers and growers are seeking higher crop yields to help balance increasing production costs. Methods/practices used to increase yield include crop zoning to suitable climates (Bunting *et al.*, 1982), improved cultivars, higher applications of fertilizers and agrochemicals, use of growth promoters/ripening agents, using modified soil management practices, growing in different media, modifying atmospheres and controlling temperature in protected cultivation, and through using irrigation and higher plant densities. These methods/practices, while increasing yield, may lower the sensory quality of the crop and adversely affect composition.

In the period 1961-79 the world cereal grain yield per hectare (ha) has increased by 26% with an increase of 42% for millet (MacKey, 1981); in the last 10 years the yield of greenhouse tomatoes in Ireland has risen by 30% to about 250 t/ha (Gormley, 1982). Similar increases have been recorded with many other crops. However, crop yields are often inversely related to quality (MacKey, 1981; Gormley *et al.*, 1973, 1982) and there are increasing consumer complaints about the quality of intensively produced food, i.e. that fruit, vegetables and other foods do not have the flavour they had when yields were lower and agricultural practices less intense; this has led to an upsurge in the demand for organically grown foods in some countries (Kramer, 1973; Knorr, 1979).

The Commission of the European Communities (1978, 1983) has expressed its concern on the intensity *versus* quality issue by launching a research programme on this topic in member states; the sensory and compositional aspects of intensively produced apples, tomatoes and poultry are being studied and it is proposed to include beef and potatoes in future programmes. Saurer (1981) has discussed some of the effects of modern agricultural methods on the quality of cereals and vegetables while Stoll (1969) emphasised the detrimental effects of excessive fertilizer applications on crop quality.

This discussion examines some of the effects of intensive production methods on the quality of plant foods; this is a wide topic and only superficial coverage can be given to many of the aspects. Most attention is given to studies where a significant amount of quality evaluation of the food produced, in terms of sensory and/or chemical and/or physical analyses, has been carried out. The impact of plant breeding and cultivars, as part of the intensive production system, is not discussed in view of the extensive nature of this area. However, it is important to note that there is considerable emphasis on

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breeding for high quality in addition to yield (Axtel, 1981) in many crops, including apples (Alston, 1981), legumes (Milner, 1973), cereals (Doussinault *et al.*, 1975) and strawberries (MacLachlan, 1981).

USE OF FERTILIZERS

Increased use of fertilizers and the timing of their application are major aspects of intensive crop production.

Wheat

There are many reports on the beneficial effect of nitrogen (N) on the protein content and protein quality of wheat; a good protein status is essential in wheats intended for bread-making. In the USA, Hunter and Stanford (1973) showed that protein content increased from 10.9% with no N to 14.3% with 168 kg N/ha. McNeal *et al* (1971) obtained a similar result and also an increase in loaf volume as did Canadian workers Kosmolak and Crowle (1980). Campbell and Davidson (1979), also in Canada, showed that grain protein content was inversely related to grain yield at any given level of N.

In Germany, Kurten (1973) found that late N increased yield in winter wheat and that Zeleny sedimentation values (an index of protein quality) were raised from 37 ml with two applications of N to 47 ml with three applications; this result was also reflected by a good loaf volume and crumb structure. Other German workers (Kampf and Gunzel, 1973) showed that basic (42-120 kg/ha) and late N (40-100 kg/ha) had only a small effect on protein status of winter and spring sown wheats; similarly the protein status of 'quality A and B Cultivars' was unaffected by N fertilization but 'quality C Cultivars' were improved (Aigner and Kurten, 1979).

Primost (1980) reported a negative correlation between yield and gluten content at high N (200 kg/ha) in Austria; sedimentation values were unaffected. Finnish workers (Elonen *et al.*, 1975) increased grain yield by 60% by N fertilization/irrigation without reducing the baking quality of the wheats; irrigation reduced Zeleny sedimentation values from 63 to 53 ml while N fertilization increased them. Data from the USSR (Boiko, 1973) showed that split applications of N increased the protein and gluten content of the wheat and also improved bread quality.

Granular applications of N (90 kg/ha) increased yield and protein content of winter wheats in the UK by 12 and 13% respectively (Pushman and Bingham, 1976); loaf volume was also increased. Follow-up foliar sprays of urea (45 kgN/ha) increased protein content by a further 12% but did not influence loaf volume or yield. Stewart (1977) reported a protein increase from 8.2 to 11.6% by the use of 192 kgN/ha in UK-grown wheat; loaf score improved from 10 to 25. Timms *et al* (1981) found that wheat with 13.4% protein gave better bread than that with 9.8%. However, no further improvement was obtained in bread made from wheat with 14.7% protein; these wheat protein levels were achieved using late urea applications and the authors conclude that high levels of late N in the absence of S fertilizer lead to available S levels becoming insufficient for 'normal' grain development.

Research in Ireland showed that the protein content of the cultivar Kleiber was raised from 11.5% (90 kgN/ha at sowing) to 12.8% (split applications, i.e. 40 at sowing + 30 + 20 kg/ha); protein quality and loaf volume were unaffected (Dwyer and Thomas, 1979). Similar results were obtained for the cultivar Copain in 1980. In 1982 more attention was given to improving the protein status of winter wheats in view of the swing by Irish farmers to growing this higher yielding wheat type. Late N and/or S fertilization had no

effect on the protein status of the cultivar Armada; however, late N produced a small increase in the grain protein contents of Copain and Guardian, i.e. from 10.5 and 8.2% to 11.2 and 8.7% respectively (Dwyer and Thomas, 1982).

Nitrogen levels up to 80 kg/ha had a favourable effect on the processing characteristics of wheat grown in trials in Belgium and also on baking properties (Legros, 1973). Further trials showed that slow release urea condensates gave wheat which produced much better bread than that produced from wheat grown using conventional NPK fertilizers (Verstraeten and Livens, 1975).

Four N fertilizer levels ranging from 0 to 107 kg/ha raised protein and gluten contents of wheat in a linear fashion from 10.2 and 6.2% to 14.0 and 9.1% respectively in trials in the United Arab Republic (Habib *et al.*, 1971). Similar trends were obtained in trials in Egypt with N levels of O to 225 kg/ha (Youssef and Abdel-Rahman, 1976) and also in experiments in some CMEA (Council for Mutual Economic Aid) countries where mean protein content (over all trials) was increased from 13.0 to 16.4% with N fertilization (Schmeider, 1979).

These data from a number of countries indicate that N fertilizers usually increase wheat yields and protein contents. However, N application does not always raise the quality of the protein in the grain and on occasions there is an inverse relationship between yield and protein status (see section on *Yield versus Quality*).

Other cereals

Application of early N to oats in the UK raised yield while late N increased protein content; however, these two parameters were negatively correlated (Welch and Yong, 1980).

Four split applications of N fertilizer (from 100-200 kg/ha) raised the protein content of rice grown in Egypt from 9.7 to 11.2% (Youssef *et al.*, 1980); grain yield and protein content were positively correlated and 150 kgN/ha was the optimum fertilizer level. Tests in the Philippines showed that up to 60 kgN/ha increased the protein content of a number of rice cultivars but only one cultivar showed a yield increase (Nangju and Datta, 1970). Studies in Japan indicated that late N impaired the quality of rice, by reducing apparent viscosity; Japanese consumers have a preference for a soft sticky rice (Yamakawa and Wasano, 1975). Similar results for N application in rice were obtained by Yamashita and Fujimoto (1974) and by Ishima *et al* (1974).

Nitrogen fertilizer levels of 13 to 134 kgN/ha increased the protein content of five pearl millet cultivars, grown in the USA, from 8.8-14.1% to 11.6-20.5% with only minimal effects on protein quality (Bailey *et al.*, 1980); starch and protein contents were inversely related. Indian workers (Deosthale *et al.*, 1972) obtained similar results for millet with yield being maximized at 120 kgN/ha, while Warsi and Wright (1973) found that late N fertilization favoured greater accumulation of protein in sorghum grain than did early N application.

These data suggest that moderate N applications have a beneficial effect on the yield and quality of oats, rice, millet and sorghum but not of rice in Japan.

Potatoes

German workers (Poletschny and Kick, 1979) showed that K fertilizer levels up to 306 kg/ha were associated with a lowering of reducing and total sugars; this improved the quality of chips made from these potatoes. High K applications raised yields but reduced the starch content of the tubers by an average of 0.5%.

Ellala et al (1971) in Finland found that increasing N (50-200 kg/ha) and K (100-400

 kgK_2O/ha) fertilization reduced specific gravity, characteristic mealiness and the amount of high quality potatoes in trials with the cultivars Bintje and Realta; no flavour effects were produced. Norwegian research (Dragland, 1980) gave similar results; increasing N (0-200 kg/ha) gave a lower tuber dry matter (DM) content and a bitter taste. However, these effects were minimal up to the N fertilizer levels giving maximum vield (< 40 kg/ha after cabbage or swedes; 120-160 kg/ha after cereals).

Experiments in Ireland (Herlihy and Carroll, 1969) revealed that N applications of 0, 50, 100 and 150 kg/ha gave corresponding tuber yields of 18, 21, 22 and 22 t/ha respectively. Phosphorus (0 to 118 kg/ha) raised yield from 18 to 22 t/ha with no response after 78 kg/ha. Potassium increased yield up to a rate of 179 kgK/ha. These fertilizer levels had no influence on organoleptic tests as reflected by panel estimates of colour, flavour and texture of boiled potatoes. Further tests, using the cultivar Arran Banner (Gately and Doyle, 1973), indicated that NPK levels of 28-60, 70 and 28-60 kg/ha respectively were most profitable from a yield/quality/return point of view; tuber DM content varied between 16-19% and higher rates of K tended to decrease it. Based on these data, moderate applications of fertilizer seem most desirable.

Tomatoes

Greenhouse tomatoes are one of the most intensively grown crops and fertilizer applications are usually accurately controlled. The data (Table 1) show that increasing base fertilizer levels reduced total yield but raised the soluble solids (SS), titratable acidity (TA) and electrical conductivity (EC) values for tomatoes grown in small plots (Gormley and Gallagher, 1974). Base fertilizer levels of 200 to 2200 gm⁻³ (at 400 g increments) did not influence the total yield, SS, TA or EC values of greenhouse tomatoes in further trials conducted in 1982 (Gormley and Maher, 1982); mean values for these parameters were 5.0%, 8.8 meq and 609 μ S respectively and were considerably lower than the values shown in Table 1. However, the average yield (Table 1) was 11.5 kgm⁻² compared with 25.3 kgm⁻² for the 1982 trial, thus reflecting a large difference in intensity. These data suggest that tomatoes from high-yielding plots have lower compositional values. The lack of response of tomato plants to base fertilizer levels in the 1982 trial suggests that once adequate K is being supplied in the liquid feeding

Base fertiliser level	Soluble solids (%)	Titratable acidity (meq) ¹	Electrical conductivity (µS) ²	Total yield (kg m ⁻²)
1	5.5	7.8	840	12.6
2	6.0	8.6	900	12.3
3	6.5	8.8	930	12.0
4	6.7	9.8	990	11.3
5	7.4	10.2	1050	9.4
F-test	***	***	***	**
SE (of mean)	0.19	0.13	17.2	0.70

TABLE 1 Composition and yield of greenhouse tomatoes grown at 5 base fertiliser levels

¹meg per 100 ml juice.

²I part juice diluted with 9 parts distilled water.

programme, the initial level in the growing medium seems of less importance at a volume of 14 litres (l) of growing medium per plant.

Increasing levels of K (180, 280, 380 mg/l) in the liquid feed had a small raising effect on tomato fruit TA and EC values, and also on yield but had a large reducing effect on the weight of non-uniformly coloured fruit (Table 2); flavour was not affected (Gormley and Maher, 1981). The values for SS, TA and EC (Table 2) are low relative to those found in trials in the early 1970s, again reflecting more intensive production in 1982.

Further tests in 1982 (Gormley and Maher, 1982) showed that nutrient solutions with EC values of 2000, 3500 and 5000 μ S gave a progressive increase in tomato fruit SS, TA, EC and firmness values and a progressive decrease in yield, for tomato plants growing in amended peat or rockwool (Table 3). The differences became smaller as the season progressed but were larger than those reported by Adams (1977) for greenhouse tomatoes grown by nutrient film technique (NFT) using solutions with EC values of '500, 4000 and 6000 μ S. Spensley *et al* (1978) in the UK obtained similar results for

TABLE 2

Effect of K concentration in the liquid feed on tomato fruit composition and yield

K in feed (mg/1)	Soluble solids (%)	Titratable acidity (meq) ¹	Electrical conductivity (µS) ²	Yield (kg m ⁻²)	Non-uniformly coloured fruit (% wt)
180	4.6	6.9	547	25.0	39.5
280	4.8	7.5	568	27.2	20.5
380	4.8	8.0	626	28.8	11.5
F-test			• -	***	***
SE (of mean)	·			0.70	2.2

Imeq per 100 g purée.

1] part purée diluted with 9 parts distilled water.

TABLE 3

The effect of three nutrient solution feeds on the composition¹ and yield of greenhouse tomatoes

Conductivity of feed (µS)	Soluble solids (%)	Titratable acidity (meq)	Electrical conductivity (µS)	Firmness ² (g)	Yield (kg m ⁻²)
2000	4.9	9.4	592	3092	22.8
3500	5.1	10.0	618	3224	22.0
5000	5.7	12.1	732	3439	18.7
F-test	***	***	*	*	*
SE	0.10	0.22	7.2	74	0.80

footnotes as in Table 2.

²g force for 5 mm fruit compression.

NFT grown fruit while earlier work by Adams *et al* (1973) showed that optimal fruit yield and composition were obtained with 250 mgN/l and 400 mgK/l in the nutrient solution.

The EC values for fruit from trials reported in Tables 2 and 3 were low; this is undesirable in view of the association of high EC values with good tomato fruit flavour (Gormley, 1972). The low values are a likely reflection of the very high yields of greenhouse tomatoes now being obtained. The EC values were similar to those found for commercially grown tomatoes in Ireland in 1981 and 1982 but were generally lower than values of 706, 726 and 786 μ S in commercially grown fruit in 1972, 1973 and 1974 respectively. Therefore, efforts must be made to raise the composition status of greenhouse tomatoes thereby promoting better flavour; fertilizer application will continue to play a significant role.

In the case of field-grown tomatoes, Gupta *et al* (1978) in India found that N levels between 75 and 150 kg/ha gave the largest increase in fruit SS and TA values while Sharman and Mann (1971) found that increasing N fertilizer levels increased juice extraction, TA, SS and Vitamin C but reduced fruit density. Presumably these results also depend on the initial fertility of the soil.

Citrus fruit

Soluble solids levels in oranges from trials in Florida were not influenced by increasing N fertilization (67-202 kg/ha) but were raised by increasing K levels (56-223 kg/ha); juice content was highest at 134 kgN/ha (Reese and Koo, 1975). A level of 157 kgK/ha gave the best orange oil and peel yield (Kesterson *et al.*, 1977). Marsh grapefruit yields (in Florida) were increased by applied N up to a rate of 168 kg/ha and fruit quality was not impaired (Smith *et al.*, 1969).

Tests in Japan (Kodama *et al.*, 1977) showed that the SS content and juice alkalinity values of mandarin oranges were raised by increased N fertilization; Vitamin C content was unaffected. Bar-Akiva (1975) in Israel found that K treatment (on trees deprived of K for a season) had a beneficial effect on splitting, fruit size and peel thickness but reduced Vitamin C content from 77 to 69 mg/100 ml. These examples suggest that moderate levels of N and K are best for citrus fruit quality and yield.

Other fruit

Low N treatments (1-2.4 meqN/l) over a four-year period gave much yellower Golden Delicious apples (Hansen, 1980) than high N (10 meqN/l) applications; low N also produced fruit with the highest SS and TA values. In the case of pineapples the SS and TA values increased with increasing N application and the best SS (14.1%) and TA (11.7 meq/100 ml) values were achieved at 10 gN/plant (Garcia, 1981).

The acid and sugar content of gooseberries was raised by increasing K applications but declined with increasing N (Hadj Hassan and Choureitah, 1973). A similar situation was found for small fruited European strawberries; the highest TA and maltose contents were obtained at a K level not above 5.0 meq/l (Choureitah and Bünemann, 1972).

Vegetables

Greenwood et al (1980) compared the effects of N fertilizer on the yield, N content and quality of 21 vegetables and agricultural crops grown in the UK. Fritz and Habben (1973), in Germany, also studied the influence of fertilization on the quality of

vegetables with emphasis on those for processing, while an ISHS Symposium (1979) studied the whole aspect of vegetable quality.

Turkmenbaev (1973), in the USSR, found that full NPK fertilization raised DM, total sugars and Vitamin C contents of cabbage; in contrast Radov (1973) found that NPK raised cabbage yields but did not influence composition.

Indian workers (Kansal *et al.*, 1981) reported that increasing urea N application (0, 30, 60, 90 kg/ha) raised the protein content of spinach; high manure levels (20 t/ha) had the opposite effect. Increases in N from 200-400 kg/ha raised carrot yields provided adequate P and K levels were maintained (German work) but did not influence DM, total sugar, carotene and Vitamin C contents (Geissler and Rudiger, 1980). In contrast Habben (1973) found that carotene, reducing sugars and nitrate contents of carrots from pot trials were increased by higher N applications. Gallagher (1965), in Ireland, using N applications of 0, 34 and 68 kg/ha found that the middle N level was the optimum rate in terms of marketable carrot yield (48 t/ha); levels of P (0-134 kg/ha) and K (0-269 kg/ha) had little effect.

Yield of beans was increased by 40 kgN/ha coupled with 60-120 kgP/ha in trials in Brazil. Total protein content varied between 18.5 and 25% (Souza *et al.*, 1973). Research on peas in the USA (Wagner, 1969) showed that P or Fe had no affect on protein status; increased Zn uptake raised the methionine content of the peas.

These data suggest that moderate fertilizer levels should be used for growing most vegetables to ensure a good yield/quality status.

Sugar-beet

Examples are given of the effect of N on the quality of sugar-beet in Ireland, the USA and in the UK.

The data in Table 4 (O'Connor, 1983) show that there was no yield response to additional N (residual N in the soil was high) beyond 45 kg/ha. Carter and Traveller (1981) in the USA found that total sucrose levels fell from 8.9 to 8.0 t/ha as N rates increased from 0 to 392 kg/ha. Extractable sucrose levels followed the same pattern. Similarly, Akeson *et al* (1979) found that root sucrose content decreased by 1.4% as N level increased from 0 to 269 kg/ha; the extractable sucrose/t beet was reduced from 144.5 kg/t at 67 kgN/ha to 128.6 kg for 269 kgN/ha. Holmes and Devine (1976) in the

impurity value N (kg/ha) Yield Sugar Impurity of roots (%) value (t/ha) (mg/100 g)

 TABLE 4

 Effect of N fertilisation on sugar-beet yield and on percentage sugar content and

	(t/ha)	(t/ha)	
0	39.2	17.7	2703
45	42.7	17.5	2802
90	42.9	17.4	3139
135	43.5	16.9	3832
SE (mean)	0.51	0.04	63

Data according to O'Connor (1983).

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UK found that average sugar content depression was 0.46% with 201 kgN/ha and 0.64% with 268 kgN/ha.

These data from three countries show that high N applications have an adverse effect on sugar-beet quality.

Nitrates

Large quantities of nitrate can accumulate in plants receiving high fertilizer applications (Lee *et al.*, 1972; Kenny and Walshe, 1975). The nitrate in the vegetables or fruit may give rise to nitrite which can be physiologically harmful to humans.

Nitrate contents of 400 to 3500 mg/kg were found in beets and 2240 to 6900 mg/kg in spinach fertilized with 0 to 448 kgN/ha (Lee *et al.*, 1972); similar results were obtained for these crops by Cantliffe (1973) in greenhouse experiments, and by Barker *et al* (1971) and Peck *et al* (1971) in upland soils in the USA.

Miyazaki *et al* (1972), in Japan, found that N applied before harvest had the greatest raising effect on tomato fruit nitrate levels; they also found that inorganic fertilizers gave higher nitrate contents in the fruit than manure. The nitrate values in these experiments were in the range 0-75 mg/kg.

Trials on lettuce, radish, and spinach (Cantliffe and Phatak, 1974) conducted in winter under poor light conditions at $NH_4 NO_3$ fertilizer levels of 0, 14.7 and 29.4 gNm² revealed that the three crops had high nitrate contents under these conditions with radish > lettuce > spinach.

Richardson (1907) reported nitrate levels of between 0-57 mg/kg in whole grain of a range of cereals. However, since then there has been relatively little published information on this topic. Gormley and Thomas (1982) found no nitrate in wheat samples from three trials: (i) 100, 130 or 160 kgN/ha at sowing, (ii) 50 and 100 kgN/ha as a late application, (iii) 48 kgN/ha at ear emergence. These results suggest that application of basic and late N to wheat does not lead to nitrate accumulation in the grain under Irish conditions.

The data above suggest that increasing N fertilizer application generally results in an increased nitrate content in fruit and vegetables but not in cereal grains.

Organic versus Inorganic

There has been much controversy regarding the quality of foods grown organically in comparison with those grown inorganically (Fryer and Simmons, 1972; Kramer, 1973). However, Barker (1975) claimed that surveys had shown no difference in the nutritive quality of horticultural produce grown organically or conventionally with modern fertilizers.

Schuphan (1974) reported that vegetables grown organically in fen or sandy soil had 23% more DM, 18% more relative protein, 28% more Vitamin C and 19% more sugar than crops grown with NPK fertilizers; however, decrease in yields ranged from 20 to 56%. Pettersson (1978) gave yield data of 34.2 and 38.2 t/ha for organic versus NPK-grown potatoes respectively; winter storage losses were 12.5% for the former and 32.2% for the latter. Rasp (1980) found that organic N (360-480 kg/ha) gave the lowest nitrate content in spinach but the highest in lettuce in comparison with inorganic (60-130 kg/ha) fertilizers; the carotene content of carrots was unaffected by fertilizer type as was the composition of asparagus. Further tests on spinach fertilized with (NH₄)₂SO₄ or dried blood indicated that there was no sensory difference between samples from plots fertilized with organic or mineral fertilizer (Maga *et al.*, 1976).

The data presented here show that the effects produced by organic Tertilizers in

comparison with inorganic are variable. In addition, there is the basic fact that all N is absorbed in the inorganic form. Nevertheless the alternative agriculture movement has gained considerable momentum (Knorr, 1979) and will continue to do so.

AGROCHEMICALS

This section deals with the effects of pesticides and growth regulators on the composition and quality of fruit, vegetables and cereals. The aspect of actual residue levels in the foods is not considered.

Herbicides

A number of workers have investigated the effect of herbicides on the nutritive value of crops. Mason *et al* (1969) found that simazine, diuron, CIPC or amitrole did not influence the DM or sugar content of blueberries, apples or peaches with the exception of a small change in the sucrose content of peaches at a simazine level of 4.48 kg/ha; Tarlapan *et al* (1975) found that simazine at a rate of 6 kg/ha reduced the Vitamin C content of raspberries in comparison with control samples. Kozlowska (1976), in Poland, showed that Afalon, Gesagard, Ramrod, Aretit or Nexoval herbicides at 1.5-3.0 kg/ha had no effect on nicotinic acid, riboflavin or thiamine content of beans; Biernat and Jasinska (1973), also in Poland, found that the riboflavin content of wheat was increased from 1.28 μ g/g for the control to 1.74-2.18 μ g/g for samples from herbicide treated plots. Carrots grown in soil treated with prometrin (2 kg/ha) had much higher total sugar, DM and Vitamin C values, and lower contents of carotene than the control samples (Dubenetskaya *et al.*, 1981); linuron at 1.5 kg/ha also reduced carotene levels in carrots (Beckmann and Pestemer, 1975).

Vergara *et al* (1970), in the Philippines, found that the application of simazine to flooded soil at flowering time increased the protein content of rice but reduced yield; the overall effect was a net reduction in protein per ha. Paul *et al* (1976) obtained similar results on rice (5 herbicides); igran at 250g/ha gave 8.2% protein in the rice, while the smallest effect was obtained with 2, 4-D (500 g/ha) which gave a protein content of 7.56%; the control sample had 6.82% protein.

Lebanese researchers (Saghir and Senzai, 1970) found that chlorbromuron, chloroxuron and prometryne herbicides had no effect on the composition and pungency of onions; similarly Russian workers (Beshanov *et al.*, 1973) reported that commercial quality of carrots, beetroot or white cabbage was not reduced by a range of herbicides.

In the case of citrus, the herbicides bromacil and terbacil did not change SS, TA or pH values in mandarin and navel oranges (Constantin and Brown, 1976) while apple composition was not affected by up to 10 kg simazine/ha (Borodulina and Shishkina, 1973). Tests on sugarcane indicated that sugar content was increased by the use of diuron, linuron and atrazine (Yeh, 1980).

Dicamba raised the protein content of wheat by up to 17%; however, baking and quality ratings were unchanged (McGuire and Lebsock, 1972). Similarly 2, 4-D or its amine salt, or its butyl ester, had no effect on flour gluten content, sedimentation value or baking characteristics; it did, however, increase wheat yield (Lysenko, 1975).

This data for a range of crops from a number of countries indicate that herbicides sometimes enhance composition and occasionally they have a detrimental effect. The enhancement may be due to better plant growth owing to the absence or reduction of weed competition.

Fungicides and Insecticides

Fungicides and insecticides generally behave in a similar fashion to herbicides in relation to their effect on the composition and quality of crops. Sweeney *et al* (1968) showed that chlordane and demetron had no effect on the composition, colour and flavour of strawberries. Kavanagh *et al* (1968) found that the use of dichlofluanid for the control of *Botrytis* in strawberries greatly increased yield compared with the control (Table 5) and had no effect on fresh fruit or canned fruit flavour even at application levels of 17.9 x 2 kg/ha. Engst *et al* (1969) found that captan-treated strawberries had higher sugar and Vitamin C contents than the controls in most seasons while in the case of apples repeated spray applications with fungicides and insecticides increased fruit weight and decreased the sugar percentage. No flavour changes were observed due to these treatments.

Spraying of greenhouse tomatoes with dichlorvos or malathion raised Vitamin C values from 16.8-19.0 mg/100g to 18.3-24.7 mg/100g; dichlorvos also increased the Vitamin C content of spinach (Zadrozinska, 1973).

A range of fungicides applied to wheat showed no negative effects on grain quality; positive effects on composition were obtained from some treatments and this may have been due to better development of the grain (Zwatz and Waltl, 1974).

TABLE 5

Effect on *Botrytis* control and strawberry fruit flavour of different rates and numbers of applications of dichlofluanid, 50% w.p.

D. 4		15 14	Fruit flavour	
Rate per application (kg/ha)	No. of applications	frust yield (t/ha)	Fresh fruit	Canned fruit
0	0	9.9	+0.911	+0.901
2.2	4	16.3	+0.29	+0.90
6.7	2	15.2	+0.75	+0.80
9.0	2	15.1	+0.33	+0.80
17.9	2	16.1	+0.88	+0.60
SE (of mean)	_	0.97	±0.27	±0.16

Data according to Kavanagh et al. (1968).

taste panel scores allotted to coded sample of control as compared with +1.0 given to the known control.

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Growth Regulators

Both growth retarders and ripening agents are considered under this heading. McDonnell and Edgerton (1970) found that neither CCC nor Alar influenced fruit size, flesh firmness or SS content of Golden Delicious apples at the concentrations used in the study. Tests on wheat (Porot'kin and Demidova, 1972) showed that CCC increased yield but the contents of protein and gluten were slightly reduced; there was also a lowering in baking and processing quality.

The use of Ethrel for ripening tomatoes (Iwahori and Lyons, 1970) had only a small reducing effect on fruit pH, TA and SS values. Similar results were obtained for tomatoes by Russo *et al* (1975) using Etephon applications of 2.9 kg/ha; they conducted taste panels and found no flavour differences between treated and untreated fruit.

Etephon at 50-200 mg/l hastened the maturity of peaches and increased Hunter a, b values and also fruit SS content; TA values were not affected (Sims *et al.*, 1974).

The data presented here indicate that the use of agrochemicals had, in general, no adverse effect on crop quality and in some cases they had an enhancing effect. Few authors report taste-panel evaluation of flavour for the various crops tested; however, research associations such as Leatherhead and Campden in the UK carry out extensive taint testing of crops/food products each year that have come from plants treated with a wide range of agrochemicals.

PLANT SPACING

Increase in plant density usually gives a rise in yield per hectare; however, the composition and quality of the crop may be influenced by the spacing treatments. Some examples of spacing x quality are given below.

Phillips (1969) in experiments initiated in Florida in 1960 found that apple tree spacings of 10×15 , 15×20 , and 25×25 ft had no effect on internal fruit quality until 1969. Fruit from the 10×15 ft spacing contained appreciably more juice and had a higher TA value than apples from trees at a wider spacing; however, SS values were lower. Foda *et al* (1977) showed that strawberry yields were highest at close plant spacing (20 cm) but SS and firmness values were unaffected by within-row spacing; these experiments were conducted in Egypt.

Gormley and Maher (1982) studied the fruit quality and yield of greenhouse tomatoes grown at a range of densities (Table 6). Yield was significantly raised at the higher plant densities while the weight of fruit with diameter >57 mm was lower (Table 6). The spacing did not influence fruit SS, TA, EC, colour or firmness values and grand means for these parameters were 4.7%, 8.2 meq, 643 μ S, 1.23 (a/b) and 2724 g respectively. Similar results were obtained in Italy for outdoor tomatoes (Postiglione and Lanza, 1978) grown at densities of 40, 60 and 80 x 10³ plants/ha; fruit weight decreased with increasing plant density but there was no difference in quality of the fruit from the different plant densities.

Tests on carrots at populations of 400 to 1000×10^3 /ha indicated that the proportion of large carrots decreased at the higher plant densities. However, plant density had no

Spacing (cm)	Plants m ⁻²	Yield to June 30 (kg m ⁻²)	% (wt) with diameter > 57 mm
45	2.92	15.2	22
50	2,62	14.2	27
55	2.39	13.1	29
60	2.19	12.9	29
65	2.02	11.8	34
70	1.87	11.6	33
F-test	_	***	**
SE (of mean)		0.32	1.84

TABLE 6

Effect of plant spacing on tomato fruit yield

effect on the sensory properties or on the concentration of sugars, carotene, nitrate and Mg (Dragland, 1978). Similarly plant densities of 140, 280 and 420 plants m^{-2} for triticale and wheat had no effect on the percentage protein or lysine content of the grain (Gebre-Mariam and Larter, 1979). In the case of soya beans, a spacing of 20 cm between the rows gave a higher protein yield (509 kg/ha) than 50 cm (295 kg/ha) and also higher oil yields, i.e. 274 vs 164 kg/ha. The percentage oil and protein in the seeds was unaffected by plant spacing (Patel *et al.*, 1978).

Results for sugar-beet grown in Ireland (O'Connor, 1983) showed that high plant densities resulted in a raised sugar content in the roots and a lower impurity value (Table 7). Yield was highest at the intermediate densities.

Similar results were obtained in the Netherlands (van der Beek and Jager, 1979); the sugar content of the roots increased as densities went from 50 to 70 x 10^3 plants/ha; further increases in density up to 150×10^3 plants/ha had only a marginal effect on composition.

These data show that it is possible to obtain improved yield in many crops by increasing plant densities; in general the composition of the fruit, vegetable or cereal is unaffected.

Plant density (plants/ha)	Yield of roots (t/ha)	Sugar (%)	Impurity value
50,000	41.6	17.2	3265
65,000	43.3	17.3	3127
80,000	42.1	17.4	3060
100,000	41.3	17.5	3025
SE (of mean)	0.33	0.05	31

	TAE	BLE 7		
Effect of plant d	lensity on the	yield and qu	ality of sugar-b	eet

SOIL MANAGEMENT

Method of soil management can greatly influence plant growth which in turn can affect yield and fruit composition. The use of herbicides removes the need for cultivation and the rootlets can explore the nutrient-rich surface areas of the soil without being damaged (Robinson, 1975); this technique works best in soils that contain a significant amount of organic matter.

Experiments in Ireland on the use of overall herbicides to manage apple orchards (trees planted 1965) have shown that this treatment gave high yields in comparison with grassing-down or clean cultivation systems for the cultivar Golden Delicious. The data (Table 8) show that the correlation coefficients between panel flavour rating and yield were generally negative while a positive relationship was found between panel flavour response and fruit SS level in most seasons (Gormley *et al.*, 1973) These data indicate that the high-yielding treatments were giving poorer flavoured fruit. Further tests on fruit of Cox's Orange Pippin and Golden Delicious from this experiment were carried out between 1972 and 1980 (Table 9) and in most cases the correlation coefficients were negative. This showed once again that fruit from high-yielding plots were less favoured by the taste panel (Gormley *et al.*, 1982)

Research in Cyprus on oranges (Economides, 1976) showed that the overall herbicide (Atrazine) plots gave lower yields compared with clean cultivated plots; there was no difference in the composition of fruit from the different plots. The lower yields may have been due to herbicide injury as a result of a low organic matter content in the sandy soil.

TABLE 8

Rank correlation co-efficients between panel flavour rating (P), percentage of soluble solids (% SS) and yield (Y) for Golden Delicious apples in the seasons 1968-70 at time of harvest

Season	$P \times \%$ SS	$P \times Y$	
1968 Rep 1	-0.48	-0.97	
Rep 3	-0.14	- 0.70	
1969 Rep 1	+0.88	-0.78	
Rep 3	+0.90	-0.72	
Rep 4	+1.00	- 0.89	
1970 Rep 1	+0.60	-0.14	
Rep 4	+0.71	+0.35	

TABLE 9

Rank correlation co-efficients between percentage of soluble solids and yield for Golden Delicious and Cox's Orange Pippin apples in 5 seasons

Season	Golden Delicious	Cox's Orange Pippin
1972	- 0.32	
1973	- 0.94	- 0.51
1974	+0.06	
1975	- 0.61	- 0.59
1979		- 0.68
1980	- 0.41	

PROTECTED CROPPING

Cropping under glass or plastic is one of the most intensive methods of production. Fertilizer applications and growing temperatures can be monitored carefully, the atmosphere in the greenhouse can be enriched with CO_2 , the plants are often grown in small volumes of substrate or in a nutrient solution (ISHS, 1977), and the whole system lends itself to the optimization of yield.

Protected cropping is carried out where outside temperatures are limiting and so is especially useful for out-of-season production. In this situation unheated crops may be put under stress by low ambient temperatures and by poor light conditions, and so the monitoring of crop quality is of paramount importance. Some data on the composition

of tomatoes grown in greenhouses in winter (in Yugoslavia) have been published by Mosorinski *et al* (1981); the mean DM content of 5.7% compares favourably with that of tomatoes grown in greenhouses in spring/summer while mean fruit K content at 2271 mg per 100 g DM was low. Unfortunately, relatively little information has been published on the sensory quality and composition of crops grown in unheated glass or plastic houses, and this therefore should be a priority for future research.

Data for the composition and/or yield of tomatoes grown in Ireland in heated glasshouses have already been given in the sections dealing with *Effects of fertilizers* (tomatoes) and in *Plant spacing*, as well as Tables 1, 2, 3 and 6. The results suggest that fruit composition values, especially EC values, have tended to fall over the last decade as yields increased. In addition, the effort made to obtain higher yields of tomatoes is also manifested by a fall-off in fruit composition values during the season (Table 10); presumably as the plants age they respond less well to increased fertilizer inputs in the middle and late parts of the season. The use of a 2-crop system may result in better fruit quality late in the season. Interplanting of the second crop normally takes place in June and cropping starts in August.

TABLE 10
Soluble solids, acidity and electrical conductivity values ¹ for
tomatoes from the Dublin market, 1981

Testing period	Soluble solids (%)	Titratable acidity (meq)	Electrical conductivity μS
April 28-May 20	4,4	8.3	701
July 8-July 30	4.2	7.9	653
Sept. 24-Oct. 19	4.3	7.0	630

¹footnotes as in Table 2.

IRRIGATION

It is widely accepted that irrigation helps to increase and/or stabilize yields; this tenet has been recently challenged by Barker *et al* (1981) who argue that absolute variance must increase as yields increase due to the combination of irrigation with modern seed/fertilizer technology. The use of irrigation can be classed broadly into two categories: (i) areas/crops where irrigation is essential in order to obtain an economic yield, and (ii) areas/crops where economic yields are usually obtained but irrigation is used to give an even higher yield. Most of the examples cited here, relating irrigation to crop composition and quality, refer to the second situation.

Danish research on potatoes (Gregersen and Jorgensen, 1973) showed that irrigation at two levels generally gave an improvement in quality and yield compared with the controls, while work in the USA (Augustin *et al.*, 1977) indicated that where irrigation management was less than optimum the NO₃ -N content of potato tubers rose from about 80-120 mg/kg at low N levels to 786 mg/kg at high fertilizer levels. In the case of sweet potatoes, supplemental irrigation caused a decrease in DM and protein content, colour of both fresh and processed sweet potatocs, and firmness of the canned product (Constantin *et al.*, 1974). Vertii and Skripka (1970), in tests in Russia, found that

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optimal irrigation and good agrotechnical practices raised the yield of hard wheat from about 0.9 to 5 t/ha; the wheat was of the highest baking quality.

Irrigation caused a decrease in SS content of Valencia oranges grown in Florida but raised fruit yields (Koo, 1979); this resulted in a lower increase in yield for SS. Tests on cucumbers in Canada (O'Sullivan, 1980) showed that irrigation had no significant effect on yield or quality with the exception of colour. In the case of tomatoes irrigated at 1, 2 or 3 week intervals, it was found that irrigation at 2-week intervals gave the maximum sound total yield; weekly irrigation gave the highest percentage of damaged fruit while 3-week intervals gave the highest SS content in the fruit (Pena *et al.*, 1978).

These data suggest that, with the possible exception of sweet potatoes, irrigation improved crop yield and had a minimal effect on composition and quality.

YIELD versus QUALITY

Some aspects of the yield vs quality issue have already been discussed for tomatoes and apples, where it has been suggested that tomato fruit composition has fallen in the last decade as yields increased and that apples from high-yielding plots had lower SS values and were less preferred by taste panels. Theoretical yield/quality effects for grain have been published by MacKey (1981). Table 11 shows the interrelationship between yield, protein content and carbohydrate content. A similar situation has been found in the case of spring and winter sown wheats in Ireland. The data (Table 12) show that the higher yielding winter varieties have a lower protein content; the quality of the protein is also lower.

Other examples of inverse yield vs quality effects have been given for protein content vs grain yield. Some examples have also been given where yield has been significantly raised without affecting quality. However, there are few examples where a large increase in yield is paralleled by a corresponding increase in quality brought about by intensive agricultural practices; such successes are usually the outcome of plant breeding. On balance, therefore, it seems that significant increases in yield brought about through intensive production practices usually result in a lowering in compositional, and perhaps sensory, quality of the products.

Protein content (%)	Carbohydrate content (%)	Grain yield kg/ha
8.0	74.5	5105
10.0	72.5	5055
12.0	70.5	5000
14.0	68.5	4945
16.0	66.5	4895
18.0	64.5	4840
20.0	62.5	4785

TABLE 11 Sacrifice in grain yield at increasing protein/decreasing carbohydrate content¹

Data according to MacKey (1981).

¹Data presupposes absence of compensating photosynthetic capacity and fixed level of fat (3%), ash (2.5%) and moisture (12%).

	Yield t/ha	Protein at 15% moisture ¹ (%)
Winter sown	7.5-8.8	9.96
Spring sown	5.0-6.3	11.16

 TABLE 12

 Yield and protein content data for winter and spring sown wheats in Ireland

¹Based on "top 20% of wheat samples" tested (1974-1980) according to data of Dwyer et al (1981).

No discussion on yield vs quality is complete without reference to maturity especially as related to peas, sweet corn and green beans. The inverse relationship between textural properties and yield for these crops has long been recognized. In most crops harvested at an immature stage there is a conflict between the requirements for processing quality and yield; for example, in the case of peas for quick freezing, the grower can expect to harvest only 75% of the maximum yield (Arthey, 1975). However, growers are rewarded financially for harvesting their pea crops at optimum maturity to offset loss of potential yield.

CONCLUSIONS

This discussion has outlined the influence of intensive production methods including the use of fertilizers, agrochemicals, different plant densities, soil management techniques, protected cropping and irrigation on the yield and quality of crops. Recognizing that this is a very broad area and that the research quoted has been carried out in many countries on a variety of crops, it is not possible to make definitive statements as to the effects of all these aspects; however, some general comments can be made as follows:

(a) Moderate levels of fertilizer seem best, on balance, for most crops in order to obtain the optimal blend of yield/quality.

(b) Application of agrochemicals had only marginal effects on crop composition and in some cases actually improved composition.

(c) High plant densities generally raised yield but usually had only a small effect on crop quality provided fertilizer application and other husbandry aspects were adequate.

(d) High crop yields were often negatively correlated with composition values and with sensory evaluation; however, it would seem that in nearly every case the high-yielding crops would still be acceptable to consumers.

(e) Producers, wholesalers, processors, regulatory agencies and particularly research workers should pay attention to the quality evaluation of intensively produced and/or high-yielding crops; such an approach will give an assurance to both the producer and consumer.

(f) Quality evaluation of crops grown under protection should receive special attention as this method of growing probably represents *the* most intensive form of crop production.

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