VG007

Investigation of the effects of planting density and nutrution on marketable yield of capsicums

Jason Olsen
Queensland Department of Primary Industries

VG007

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Level 6
7 Merriwa Street
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Telephone: (02) 9418 2200
Fax: (02) 9418 1352

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1. SUMMARY

(a) Industry Summary

Nitrogen uptake and utilisation by bell pepper in subtropical Australia

A nutrient balance mass flow study for capsicums grown over two seasons revealed that phosphorus and nitrogen were applied well in excess of crop demand (65 to 68 kg/ha for P and 52 to 57 kg/ha for N). Potassium and sulphur were also applied above plant requirements by 24 to 32 kg/ha and 19 to 24 kg/ha, respectively. Values of calcium and magnesium were negative indicating nett losses from the soil, but these elements are usually supplied when dolomite is applied to the soil to increase pH prior to planting.

The high N demand of capsicums was confirmed from this study. It was concluded that the existing rate of N recommended for Bundaberg capsicum crops (approximately 22 kg/ha) is not excessive in terms of securing maximum harvested yields as highest yields in the study were attained at approximately 210 to 280 kg N/ha. However, 46 to 91 kg/ha of applied N was not recovered in the crop at these rates. The fate of this non-recovered N is not known, but the potential exists for it to be either leached down the soil profile and contribute to pollution of the ground water, or be denitrified and lost to the atmosphere.

This study provides information on total nutrient requirements of a capsicum crop and forms a basis on which growers can tailor fertiliser application rates to avoid wastage of fertiliser inputs with possible pollution effects.

Petiole sap nitrate better than total N in dried leaf as an indicator of N status of bell pepper in subtropical Australia

Rapid analysis of sap in leaf petioles is becoming a popular technique of monitoring crop nutrition. However, compared with traditional results obtained from digestion and Kjeldahl methods used for standard leaf tissues, sap data is relatively unproven. This study was conducted to assess the usefulness of both petiole sap nitrate and total N in dried leaves in determining N status and yield potential of capsicum.

It was shown that nitrate determined in petiole sap of capsicum leaves was approximately five times more sensitive to changes in N application than total N determined in leaves. Sap nitrate was found to be a more reliable and consistent indicator of yield potential than total N in dried leaves. An optimum sap nitrate range and a desirable sap K concentration were determined at key phenological stages in the crop's life.

This information is of practical benefit to industry as it elucidates the benefits of sap over tissue analysis and gives creditability to the former method, particularly for N and K analysis. Definition of desirable concentration ranges for N and K in petiole sap at several phenological stages of the crop's life provides a benchmark to which plant nutrient status at the time of sampling can be compared.

Capsicum planting density and cultivar study

A planting density study was carried out to define the optimum plant spacing for four commercial capsicum cultivars (Target, Domino, Cordoba, Bell Tower) grown over two seasons. Planting densities of 30 000 plants per hectare in autumn and 40 000 plants per hectare in spring were recommended. A wider plant spacing was necessary in autumn due to more shading than in spring due to the northerly slant of the sun in autumn and winter with an associated higher incidence of diseases such as bacterial spot. Therefore, a slightly more open canopy is necessary in autumn to ensure adequate spray penetration for disease control. Additionally, fruit size in autumn tended to be below that acceptable for markets, so a slightly lower planting density than for spring was considered necessary to increase fruit size. In spring, 40 000 plants per hectare gave the best combination of marketable yield, optimum fruit size, plant spacing and orientation for shading and spray penetration and economical considerations (e.g. cost of seedlings).

Comparison of the four standard cultivars grown at commercial planting densities (30 000 to 40 000 plants/hectare) showed that Target was the best performer in the autumn season, whereas Domino yielded most cartons in spring.

This information is of practical benefit to capsicum growers wishing to maximise yields through planting the highest yielding cultivars at the optimum planting density.

Management practices to reduce incidence of "mature plant collapse"

Avoiding plant stresses imparted by over-watering, under-watering and temperature extremes is necessary to reduce the incidence of "mature plant collapse". Use of tensiometers for irrigation scheduling and white plastic mulch for warm-season planting times are strongly recommended.

(b) Technical Summary

Nitrogen uptake and utilisation by bell pepper in subtropical Australia

Concern over the pollution potential of nitrogen (N) fertilisers has prompted studies of the utilisation efficiency of applied N by crops. This study was conducted to determine the efficiency of N usage by bell pepper (*Capsicum annuum L.*) grown with plastic mulch and trickle irrigation, and to define a rate of applied N which is equal to uptake by the crop.

Nitrogen uptake was equal to the applied rate when 140 kg/ha was applied. Plant uptake of elements increased with applied N, and, at 280 kg/ha, were ranked as follows: K>N>Ca>Mg>S>P. Fruit accumulated the greatest proportion of K, N, and P (40 to 64%, 40 to 64%, 49 to 76% respectively), and only a comparatively small amount of Ca (6 to 7%). The efficiency of fruit production from absorbed applied N declined with increasing N rate. District standard rates of P, N, K, and S application exceeded uptake by plants grown at an equivalent N rate (differences of 68 and 65 kg P, 57 and 52 kg N, 32 and 24 kg K, and 19 and 24 kg S for spring and autumn, respectively). Because of the importance of pepper yield as a determinant in economic outcome and the relatively low cost of fertiliser N, application rates in excess of 140 kg N/ha are likely to continue by district growers in an attempt to maximise yield.

Petiole sap nitrate better than total N in dried leaf as an indicator of N status of bell pepper in subtropical Australia.

This study was conducted to assess the usefulness of both petiole sap nitrate and total N in dried leaf in determining N status and yield potential of bell pepper (*Capsicum annuum L.*) grown with plastic mulch and trickle irrigation in subtropical Australia. Sap nitrate was approximately five times more sensitive to changes in N application than total N. Quadratic square root relationships between marketable fruit yield and petiole sap nitrate were closer and more useful than linear relationships between marketable fruit yield and dried leaf total N.

Sap nitrate concentrations associated with 95 and 100% maximum marketable fruit yield increased from bud development (5010 to 6000 mg L^{-1} spring, 4980 to 5280 mg L^{-1} autumn) to first anthesis (6220 to 7065 mg L^{-1} spring, 5550 to 6000 mg L^{-1} autumn). The range progressively decreased after first anthesis to 1640 to 2800 mg L^{-1} and 520 to 1220 mg L^{-1} at fruit set, for spring and autumn, respectively.

It was concluded that sap nitrate was a better indicator of plant N status and yield potential than dried leaf total N for bell pepper in subtropical Australia. A desirable petiole sap K concentration of greater than 4800 mg L^{-1} was proposed by correlating sap K with yield responses.

Bell pepper planting density and cultivar study

A planting density study was carried out to investigate the effect of planting density on marketable yield of four commercial bell pepper cultivars (Target, Domino, Cordoba, Bell Tower) grown over spring and autumn seasons. Increasing plant number to 180,000 plants per hectare decreased marketable yield in autumn, whereas in spring, closer plant spacing increased yield to approximately 40,000 plants per hectare, but did not significantly increase yield at higher densities. Number of marketable fruit per hectare increased with planting density in spring but decreased in autumn and average weight of marketable fruit was much heavier in spring than in autumn. Based on marketable yield and average fruit size data, planting densities at 30,000 plants per hectare in autumn and 40,000 plants per hectare in spring are recommended. A lower planting density in autumn than in spring is important to allow adequate spray penetration for diseases control in autumn due to a more open canopy.

Comparison of the four standard cultivars grown at commercial planting densities (30,000 to 40,000 plants/ha) showed that Target produced the greatest weight of marketable fruit in autumn, whereas Domino was best in spring.

"Mature plant collapse"

A Pythium/Fusarium complex associated with plant roots in an aborted planting density trial in spring 1991 directed attention towards management practices to follow to reduce incidence of the disease. Stress reduction (e.g. soil oxygen deficit, soil water deficit, temperature extremes) is necessary to mitigate spread of the disease.

2. RECOMMENDATIONS

(a) Extension/adoption by industry of research findings

Nitrogen uptake and utilisation by bell pepper in subtropical Australia

(i) What are the research findings and practical results?

Total plant uptake of various nutrients was determined for high yielding capsicum crops over two seasons. Amounts of various nutrients (in kg/ha) taken up by the crop were as follows: potassium K (210) > nitrogen N (195) > calcium Ca (78) > magnesium Mg (46) > sulphur S (34) > phosphorus P (20) for spring; K (205) > N (189) > Ca (76) > Mg (34) > S (27) > P (22) for autumn. When these values were compared with district standard rates of application of the same nutrients, a nutrient balance based on mass flow data was established. The two elements applied far in excess of plant requirements were P and N, with rates of application exceeding rates of crop uptake by 65 to 68 kg/p/ha and 52 to 57 kg N/ha. Potassium and S were also applied above plant requirement by 24 to 32 kg/ha and 19 to 24 kg/ha, respectively. Values of Ca and Mg were negative indicating nett losses from the soil, both these elements are supplied with dolomite application to increase soil pH prior to planting.

Increasing rates of applied fertiliser N (from 0 to 280 kg/ha) were compared to N uptake by the crop. The N rate at which uptake was equal to amount applied was 140 kg N/ha.

From this study, the high N demand of capsicums was confirmed. The existing rate of N recommended for Bundaberg capsicum crops (approximately 220 kg/ha) is not excessive in terms of securing maximum harvested yields as highest yields in the study were attained at approximately 210 to 280 kg N/ha. However, 46 to 91 kg/ha of applied N was not recovered in the crop at these rates. The fate of this non-recovered N is not known, but the potential exists for it to be either leached down the soil profile and contribute to pollution of the groundwater, or be denitrified and lost to the atmosphere.

(ii). How can industry adopt these findings?

By providing information on total nutrient requirements of a capsicum crop, growers have a basis on which to tailor fertiliser application rates. Given that P and N were the elements applied far in excess of crop needs, attention needs to be given to the current application rates of these nutrients. Phosphorus is usually applied as a single basal dressing prior to planting and does not leach through the soil profile. In this way, P remains available in the soil for subsequent crops. Consideration needs to be given to rates of P applied to the previous crops before applying a standard P rate to any given crop. The practical implications of applying less N to pepper crops in order to balance supply and demand is difficult to sell to industry. The importance of marketable yield as a determinant of economic outcome and the comparatively low cost of fertilisers which contain N (6 to 7% of the total variable costs in growing the crop) are factors which are likely to restrict any impetus for decreasing N usage. Use of fertigation (frequent and small applications of soluble fertiliser) is an important option in managing N fertiliser addition. Use of fertigation with regular sap nitrate monitoring are methods for improving N utilisation by crops. These methods have been embraced by many growers and are currently being promoted by the DPI. Concern over the pollution potential of N fertilisers due to leaching into underground water supplies (84% of Bundaberg's municipal water is from underground sources) is good reason to more accurately balance N fertiliser inputs with crop uptake. Otherwise, as in certain parts of Europe, environmental protection legislation limiting fertiliser addition may be introduced to protect natural resources for future generations.

(iii) How has/will information be extended to industry?

Dissemination to industry has been by addressing grower meetings, publication of articles in grower publications (e.g. Queensland Fruit and Vegetable News, 22/10/92) and via a capsicum field day (held at Bundaberg Research Station on 28/11/91).

Petiole sap nitrate better than total N in dried leaf as an indicator of N status of bell pepper in subtropical Australia

(i) What are the research findings and practical results?

Analysis of plant tissues, such as the youngest mature leaf blade, has traditionally been used as a management tool for monitoring and evaluating the nutrient status of crops. Development of methods of the rapid analysis of sap and their assessment for use either in the laboratory or on-farm has recently highlighted the benefits of the sap test over dried leaf analysis. This study was conducted to assess the usefulness of both petiole sap nitrate and total N in dried leaf in determining N status and yield potential of capsicum. It was shown that nitrate determined in petiole sap of capsicum leaves was approximately five times more sensitive to changes in N application than total N determined in the youngest mature leaf blades plus petioles (YMB+P). Sap nitrate was found to be a more reliable and consistent indicator of yield potential than total N in dried leaves.

For a commonly used fertiliser application strategy (60% of N applied pre-fruit-set and 40% after), sap nitrate concentrations associated with 95 and 100% of maximum marketable fruit yield increased from bud development (5010 to 6000 mg/L spring, 4980 to 5280 mg/L autumn) to first anthesis (6220 to 7065 mg/L spring, 5550 to 6000 mg/L autumn). The range progressively decreased after first anthesis to 1640 to 2800 mg/L, and 520 to 1220 mg/L at fruit set, for spring and autumn seasons respectively.

A desirable petiole sap K concentration of greater than 4800 mg/L was proposed.

(ii) How can industry adopt these findings?

Due to the high cost of tissue analysis and the considerable time taken to attain results (due to the requirement of oven drying and digesting plant material), emphasis has been placed in recent years on the less expensive and faster sap analysis methods. However hitherto, quality assurance of these sap tests (in terms of their ability in reflecting the nutrient status of the crop and yield potential) compared with conventional tissue analysis has remained unresearched and lacked definitive results. For example, this work demonstrated that petiole sap was approximately five times more sensitive to changes in N application than total N determined in plant tissues, and unequivocally demonstrated the superiority of sap in determining N status of the crop.

Elucidation of the benefits of sap over tissue analysis gives credibility to the former system, particularly for N and K analysis. Tissue analysis still plays a role for certain elements (such as the micronutrients) which cannot be easily determined in sap.

Definition of desirable concentration ranges for N and K in petiole sap at several phenological stages of the crop's life provides a benchmark to which plant nutrient status at the time of sampling can be compared. As for critical tissue concentrations for many nutrients, which appear in plant nutrition texts, desirable sap concentrations need to be derived in order to assess the nutrient status of the crop.

(iii) How has/will information be extended to industry?

Dissemination to industry has been by addressing grower meetings, publication of articles in grower publications (e.g. Queensland Fruit and Vegetable News, 22/10/92) and via a capsicum field day (held at Bundaberg Research Station on 28/11/91). Local consultants have been informed of desirable sap ranges for nitrate and potassium.

Capsicum planting density and cultivar study

(i) What are the research findings and practical results?

Number of plants per hectare (planting density) significantly effected yield of four commercially available capsicum cultivar (Target, Domino, Cordoba, Bell Tower) grown over two seasons (autumn 1990 and spring 1992) at Bundaberg Research Station. Planting densities of 30 000 plants per hectare in autumn and 40 000 plants per hectare in spring were recommended. A wider plant spacing was necessary in autumn due to more shading than in spring due to the northerly slant of the sun in autumn and winter with an associated higher incidence of diseases such as bacterial spot. Therefore, a slightly more open canopy is necessary in autumn to ensure adequate spray penetration for disease control. Additionally, fruit size in autumn tended to be below that acceptable for markets, so a slightly lower planting density than for spring was considered necessary to increase fruit size.

In spring, 40 000 plants per hectare gave the best combination of marketable yield, optimum fruit size, plant spacing and orientation for shading and spray penetration and economical considerations (cost of seedlings per hectare).

As an adjunct to the planting density study, four commonly grown standard commercial cultivars (Target, Domino, Cordoba, and Bell Tower) were compared over two growing reasons (autumn 1990 and spring 1992) for commercial yields at Bundaberg Research Station. At the commercial planting destinies densities selected (30 000 to 40 000 plants per hectare), Target was the best performer in the autumn season, whereas Domino yielded more cartons in spring. With the exception of Domino, all cultivars produced fewer cartons in spring than in autumn. Higher autumn production was associated with a greater number of marketable fruit than in spring which may relate to poor pollination in spring due to strong winds at flowering. Out of the four cultivars, total yield of Bell Tower was consistently lower than the other cultivars over both seasons.

In spring 1991, a planting density and cultivar trial was abandoned at harvest due to severe plant losses from the disease "mature plant collapse". The symptoms of this disease include wilting during the warm part of the day, general yellowing of the leaves, stunting and finally wilting (usually at fruit set). The fungi found in association with the disease include Pythium and Fusarium species, but the main cause of the disease is due to stress (e.g. over-watering, under-watering, temperature extremes). "Mature plant collapse" in capsicums was widespread in the Bundaberg district in spring 1991, killing up to 50% of plants. A field day was held at Bundaberg Research Station (28/11/91) to highlight management practices to employ in managing the disease (e.g. proper use of tensiometers, reflective or white plastic mulch where planting at warm times at the year).

(ii) How can industry adopt these findings?

This study investigated the effect of a wide range of plant densities on marketable yield of capsicum over two growing seasons. Definition of the optimum planting density is of direct use by industry, so that optimum yields, high fruit quality and satisfactory disease management are maintained. The finding that a lower planting density in autumn than in spring gave higher yields is useful to growers as savings in planting costs and better disease control (through more efficient spray penetration into the row) are off-shoots of this recommendation.

This study also assessed currently available commercial capsicum cultivars over spring and autumn seasons and reported the superior yields attained by Target and Domino. This information is valuable to industry and farmers who may not otherwise have access to such information.

The failed planting density trial carried out in spring 1991 (due to the disease "mature plant collapse") provided useful information to the farming community on the nature of the disease, what causes it, and agronomic practices to be employed which minimise its presence. A field day (28/11/91) held at Bundaberg Research Station emphasised the importance of proper water management in preventing the disease. Many growers over-water their crops in the early stages of the crop's life and under-water near maturity. Installation of tensiometers takes the guess-work out of water management, imparts less stress on the crop (both over and under watering) and minimises the chance of root diseases such as "mature plant collapse". Other recommendations such as use of white or reflective plastic mulch to reduce soil temperatures in late summer (early autumn) plantings was discussed. The pros and cons of using chemical treatments (such as quintozene and phosphorous acid) after the occurrence of the disease were discussed. However, the main message was to establish a soil environment which promotes root growth and reduced root stress.

(iii) How has/will information be extended to industry?

Dissemination to industry has been by addressing grower meetings, written articles revealing results (e.g. Queensland Fruit and Vegetable News, 23/5/92, 2 in press) and via a capsicum field day (at Bundaberg Research Station on 28/11/91).

(b) Directions for future research and/or activities supported by the HRDC

Capsicum nutrition work - N utilisation and sap nitrate

Partly as a consequence of the findings of this research for the need to improve N and P utilisation efficiency by capsicum crops under an intensive production system and the recognition of elevated nitrate concentration in some bores in the Bundaberg district, a joint funding proposal was put forward to various funding bodies (Land and Water Research and Development Corporation/Horticultural Research and Development Corporation/Queensland Fruit and Vegetable Growers/Incitec) for financial assistance to fund a project which aims to investigate and develop sustainable systems for intensively grown crops. The proposal ("Development of sustainable intensive crop production systems") involves scientists from a broad range of disciplines (agronomy, soil hydrology, geology, solute modelling, nematology, pathology) from several institutions (DPI(Q), CSIRO, BSES, Uni Qld).

LWRRDC are asked to fund aspects of the work which examine leaching of nitrate and pesticides into underground aquifers from sugar cane and vegetable crops. An initial survey (or "snapshot") will be conducted to establish the degree to which Bundaberg's underground water is contaminated. Process experimentation will be carried out at 3 sites (2 sugar cane, 1 vegetables), to investigate nitrate movement from the soil profile to the vadose zone. Water flow models will be used to predict the fate of this nitrate. HRDC/QFVG/Incitec are asked to fund agronomic aspects of the work which cover soil ecology, nematology and pathology for a range of difference vegetable crops and management systems.

Funding for this integrated project has been approved by LWRRDC and QFVG and is currently being considered by Incitec and HRDC.

The project aims to achieve the following objectives in each year of the project.

Year 1:

- Assess existing and alternative farming practices aimed at minimising nitrogen and phosphorus inputs but maximising yield.

- To examine the impact of various crop rotation practices on the population dynamics of root-knot nematode. This work will help determine the susceptibility of various crop cultivars and rotation crops to the races of root-knot nematodes. This methodology would require regularly sampling growers' fields and experimental plots set-up to study the soil ecological aspects of the project.

- By using a monitoring approach of growers' fields and experimental plots, to identify key disease and root development factors involved in yield declines and mature plant wilts for a range of vegetable crops.

Year 2

- To conduct field and pot trials to examine alternative strategies for nitrogen and phosphorus management. Possible strategies include aspects of fertiliser placement, rotation sequence, vesicular asbuscular mycorrhizae (VAM) inoculation, fertigation.

- To continue the nematode and root pathogen survey methodology developed in 1993/94.

- To identify the effects of subclinical root infections on yield.

Year 3

- To test the best alternative strategies for nitrogen and phosphorus management on a field basis. Investigate the possibility of a "Super-VAM" strain which could be commercially marketed for inoculation in seedling mixes of VAM-dependant vegetable crops.

- To determine the practical viability of re-using plastic mulch/trickle irrigation beds through a system of root-networking of suitable previous rotation crops to minimise the requirement for nitrogen and phosphorus fertiliser inputs.

- Treatments will be determined from the results of work in Years 1 and 2, and results from two other projects- (1) Development of microbial products for biological control of root-knot nematode (QDPI/Incitec) and (2) Nematode control with organic amendments and rotation crops (new QFVG/HRDC/RIRDC project).

- To test the effectiveness of resistant rotation crops, organic treatments and biological control agents in managing root-knot nematode in vegetables.

- To test the effects of agronomic practices such as planting, irrigation and crop rotation on root development and root infections.

- To test biocontrol and chemical agents which would be suitable for a sustainable intensive vegetable production system.

Capsicum planting density and cultivar study

Definition of new optimum planting densities may need to be made in the future with release of new cultivars. Similarly, these new cultivars will need to be assessed in terms of yield performance with contemporary cultivars. Such work is not planned within the next three years.

Mature plant collapse in capsicum is a disease associated with management practices adopted by industry. Suitable management practices have been recommended as a result of this work.

(c) Financial/commercial benefits of adoption of research findings.

Capsicum nutrition work - N utilisation and sap nitrate

Definition of nutrient requirements of capsicum crops through mass flow studies and establishment of desirable sap nitrate concentrations are techniques for minimising overuse and wastage of fertiliser inputs. However, the comparatively low cost of fertilisers which contain N (6 to 7% of the total variable costs in growing the crop) is a major determinant in maintaining comparatively high rates of application as standard industry practice.

Given that some savings in fertiliser nutrients (particularly N and P) are achievable as a direct result of this work, a more substantial commercial benefit will be from an improved public perception of growers/industry taking a pro-active role in minimising off-farm contamination from agricultural pollutants. By directing money towards research into establishing the degree to which fertiliser is over-used (N utilisation study) and methods for defining plant requirements (sap nitrate study), Bundaberg Fruit and Vegetable Growers' Association and HRDC have taken important steps forward in conserving the vision that Australian horticultural produce is "clean and green".

Capsicum planting density and cultivar trials

The financial/commercial benefits of adopting the optimum planting density research findings are as follows:

(1) optimise marketable yield
(2) optimise fruit size for market requirements
(3) optimise variable input costs (e.g. seedlings, fertiliser, plastic mulch, T-tape etc) by maximising yield per hectare
(4) optimise disease control by consideration of efficiency of spray penetration with regard to disease and pest control.

Economic advantages are associated with knowing the highest producing cultivars for spring or autumn production.

Methods for control of root disease such as "mature plant collapse" is necessary in maximising economic returns.

3. TECHNICAL REPORT(S)

Capsicum nutrition work - N utilisation and sap nitrate

The following refereed scientific paper has been published from this work in the stated international journal: Olsen, J K, Lyons D J, and Kelly M M (1993). Nitrogen uptake and utilisation by bell pepper in subtropical Australia. Journal of Plant Nutrition. 16 (1), 177-193. A reprint of this published paper is presented in **Appendix A**.

A paper which compares sap nitrate with total N in dried leaves and provides optimum petiole sap nitrate concentrations has been submitted (14/4/93) to the refereed international scientific journal "Plant and Soil" as follows;
Olsen, J K and Lyons D J (1993). Petiole sap nitrate better than total N in dried leaf as an indicator of N status of bell pepper in subtropical Australia. Plant and Soil. Submitted.
A final draft of this submitted paper is presented in **Appendix B**.

A technical feature published (22/10/92) in Queensland Fruit and Vegetable News documenting desirable concentration of nitrate and K in capsicum petiole sap is presented in **Appendix C** as follow:
Olsen, J K and Lyons, D J (1992). Desirable levels of nitrogen and potassium in capsicum sap. Queensland Fruit and Vegetable News 22/10/92.

Capsicum planting density and cultivar trials

A technical feature to be published in Queensland Fruit and Vegetable news which defines optimum planting density for capsicums has been submitted for publishing (refer to **Appendix D**). The article is as follows:
Olsen, J K, Gillespie, D and Schaefer, J T (1993).
Optimum planting density for capsicums - 30 000 per hectare autumn, 40 000 per hectare spring. Queensland Fruit and Vegetable News. Submitted.

Technical documentation of the best capsicum cultivars for spring and autumn seasons (**Appendix E**) has been submitted to Queensland Fruit and Vegetable News as follows:
Olsen, J K, Gillespie, D and Schaefer, J T (1993).
Which capsicum cultivars to plant in spring or autumn? Queensland Fruit and Vegetable News. Submitted.

A description of the capsicum disease "mature plant collapse" and recommendations for its control was published in Queensland Fruit and Vegetable News (**Appendix F**) as follows:
Olsen, J and Vawdrey, L (1992). Mature capsicum collapse. Queensland Fruit and Vegetable News. 23/5/92.

Field day information

Information provided at a capsicum field day held at Bundaberg Research Station which presented field trial results and accompanying field plots is shown in **Appendix G**.

Appendix A

JOURNAL OF PLANT NUTRITION, 16(1), 177-193 (1993)

NITROGEN UPTAKE AND UTILIZATION BY BELL PEPPER IN SUBTROPICAL AUSTRALIA[1]

J. K. Olsen[2], D. J. Lyons[3], and M. M. Kelly[2]

2. *QDPI Research Station, MS 108, Ashfield Road, Bundaberg, QLD 4670, Australia*

3. *QDPI Agricultural Research Laboratories, Meiers, Indooroopilly, QLD 4068, Australia*

ABSTRACT: Concern over the pollution potential of nitrogen (N) fertilisers has prompted studies of the utilisation efficiency of applied N by crops. This study was conducted to determine the efficiency of N usage by bell pepper (*Capsicum annuum* L.) grown with plastic mulch and trickle irrigation, and to define a rate of applied N which is equal to uptake by the crop. The relationships between applied N (0, 70, 140, 210, and 280 kg/ha), nutrient uptake, and yield for spring and autumn bell pepper crops grown on a major soil type (Tropeptic Eutrustox) in the Bundaberg region of subtropical Australia were investigated. Maximum dry weight yield of fruit, leaves, roots, and stems corresponded with N_{210} to N_{280} for both spring and autumn crops. In addition, maximum fresh weight of marketable fruit corresponded with N_{210} to N_{280} for both seasons. Nitrogen uptake was equal to the applied rate at N_{140}. Plant uptake of elements increased with applied N and, at N280, were ranked as follows: K> N> Ca> Mg > S > P. Fruit accumulated the greatest proportion of K, N, and P (40 to 64%, 40 to 64%, 49 to 76%, respectively), and only a comparatively small amount of Ca (6 to 7%). The efficiency of fruit production from absorbed applied N declined with increasing N rate. District standard rates of P, N, K, and S application exceeded uptake by plants grown at an equivalent N rate (differences of 68 and 65 kg P, 57

1. Jointly funded by Bundaberg Fruit and Vegetable Growers' Association and Horticultural Research and Development Corporation.

218-K, 47-S, 11-Ca, and 0-Mg; J. Hall, 1991, personal communication) are admininstered both as a basal application and by fertigation. Foliar application of calcium nitrate [$Ca(NO_3)_2$] is sometimes made on hot, windy days for prevention of "blossom-end rot". Use of dolomite [$CaMg(CO_3)_2$] to correct low pH, supplies additional Ca and Mg to the soil.

Bundaberg district peppers are mainly grown in acidic, sandy Ultisol (pH 5.0 to 6.0) and Tropeptic Eutrvstox (pH 5.5 to 6.5) soils (Glanville et al., 1991). Non-point sources have been identified as the dominant source of N contamination in groundwater bores underlying Bundaberg district agricultural areas (F. Sunners, 1992, personal communication). As NO_3 concentrations in some bores are close to the current safe potable limit for humans (45 mg NO_3/L, W.H.O. 1984), there is a need to more closely match N usage to crop needs.

The major objectives of the present study of peppers grown with plastic mulch were to (1) recommend a rate of applied N for maximum yields, (2) determine the efficiency of N usage, (3) determine an N rate which is equal to uptake by the crop, and (4) measure amounts of nutrients absorbed by pepper at a range of N rates and compare these amounts with district standard applied rates.

MATERIALS AND METHODS

Two experiments were conducted on a Tropeptic Eutrustox soil (pH 7.0 to 7.1) during the spring of 1990 and autumn of 1991 at the Bundaberg Research Station (24°51'S., 152°24'E.), Queensland, Australia. Densely sown sorghum cover crops (mown and raked off prior to land preparation) were grown to deplete soil nutrients. Chemical analysis of the surface 15 cm of the depleted soils indicated deficiencies in both NO_3 and K (Table 1).

For both experiments, basal fertiliser (172 kg P/ha, 390 kg Ca/ha, and 215 kg S/ha as superphosphate), and nematicide (5.56 kg/ha fenamiphos) were incorporated into raised beds two weeks prior to planting. Trickle irrigation tape was laid on top of beds and covered with 0.038-mm polyethylene mulch (black in spring and white in autumn).

Pepper seedlings (cultivar 'Bell Tower') were transplanted into the field on 27/9/90 and 12/3/91 (spring and autumn, respectively) in 80-plant plots arranged in a randomised, complete block design incorporating five N treatments and four blocks. Plants were arranged in double rows 30 cm apart with 33 cm between plants in each row. Bed centres were 1.5 m apart, giving a plant density of 40,400 plants/ha. Boron (0.5 kg/ha) and Mo (0.6 kg/ha) were applied as separate foliar sprays two and three weeks after transplanting, respectively.

Nitrogen treatments (0, 70, 140, 210, or 280 kg/ha) and K (200kg/ha) were applied through the trickle irrigation system as urea, KNO_3, and KCl, depending on N treatment. A total of 10 fertigations were made so that 10% of total nutrients were applied per fertigation. Sixty percent of the total N and K were applied in weekly fertigations prior to fruit set (average fruit diameter 20 mm), whereas the remaining 40% was supplied in four applications between fruit set and harvest.

The following pesticides were applied as required: methomyl (450 g/ha) and endosulfan (665 g/ha) for lepidopterous insects; copper hydroxide (2000 g/ha) and mancozeb (1600 g/ha) for bacterial spot (*Xanthomonas campestris* pv *vesicatoria*); propargite (300 g/ha) for two-spotted mite (*Tetranychus urticae* Koch); and pirimicarb (500 g/ha) for green peach aphid [*Myzus persicae* (Sulzer)]. Irrigation water was applied to maintain tensiometer suction in the root zone (0 to 15 cm) between 0.01 and 0.03 MPa.

Half of each plot was randomly taken for destructive harvests, the plants being partitioned into fruit, leaves, stems, and roots. Fruit was harvested from the remaining half of each plot on five occasions, graded, and weighed. Prior to the autumn harvest, soil samples (0 to 15 cm) were taken for N analysis from bed centres of those subplots allocated for destructive harvest. Twenty plants per subplot were destructively harvested 15 weeks after the spring transplanting, whereas 10 plants per subplot were destructively harvested 19 weeks after transplanting from the autumn trial. Destructive harvesting involved gently lifting every second (spring) or fourth (autumn) datum plant from moist soil. Extracted plants were washed with deionised water and partitioned into fruit (including immature fruit and flowers), leaves (leaf blades plus petioles), stems, and roots. All plant parts were dried in a gas fired oven at 60°C, weighed, and then ground through 1-mm mesh with a stainless steel mill. Samples were dried again at 105°C before chemical analysis. Nitrogen and P were determined by automated colorimetry (O'Neill and Webb, 1970), whereas Ca, Mg, K, and S were determined using X-ray fluorescence spectrometry.

Fresh weight of marketable fruit was recorded over five harvests (12, 19, 23/12/90 and 2, 9/1/91 for spring; 6, 13, 27/6/91 and 8, 19/7/91 for autumn).

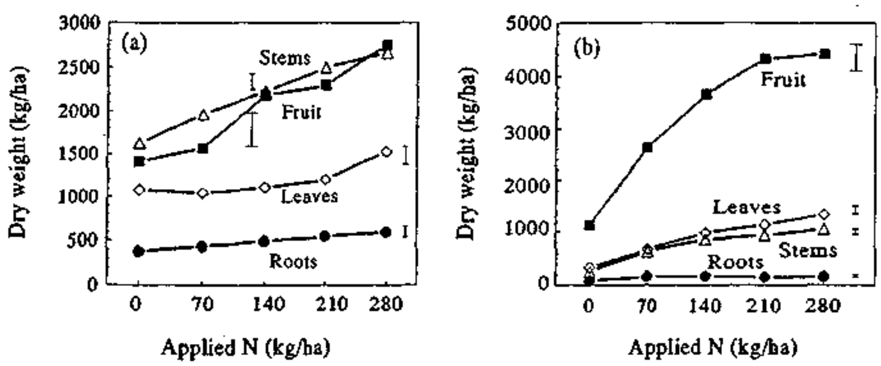


FIGURE 1. Effect of Applied N on Dry Weight of Various Bell Pepper Plant Parts for (a) Spring 1990 or (b) Autumn 1991 Crops. Vertical Bars Represent the L.S.D.s for the Difference between any Two Means (P=0.05).

have delayed the onset of fruiting and given rise to large bushes with high stem dry weights and low fruit dry weights.

Fresh weight of marketable fruit significantly increased ($P < 0.05$) with applied N in both seasons; although the difference between N_{210} and N_{280} was not significant in either season (Fig. 2).

Nitrogen uptake by the crop and total dry matter yield (Fig. 3) were positively correlated ($R^2 = 0.92$ in spring; $R^2 = 0.97$ in autumn). The fact that plateaux were not attained, even at comparatively high levels of absorbed N (>200 kg/ha), showed the substantial ability of the crop to convert absorbed N to dry matter. Slopes of the regression equations for spring and autumn were significantly different ($P < 0.05$).

Agronomic efficiency values [Equation 1] indicated that the autumn crop became less efficient in utilising applied N for fruit production as more was applied, whereas no significant trend was apparent for spring (Table 2). For every kg of N applied to the autumn crop at N_{70}, 21.7 kg of oven dry fruit were produced, while only 11.8 kg were produced for every kg applied at N_{280}. The generally lower values in spring than in autumn indicate a lower efficiency of fruit production from applied N in the former season.

TABLE 2. Relationships between Applied N and Uptake Efficiency Parameters for Spring and Autumn Bell Pepper Crops.

Applied N (kg/ha)	Agronomic efficiency† (kg/kg)		Apparent recovery‡ (%)		Physiological efficiency§ (kg/kg)	
	Spring¶	Autumn	Spring	Autumn	Spring	Autumn
70	2.25	21.7[a]	16.1	71.3	30.1	31.1[a]
140	5.57	18.2[ab]	30.1	68.3	19.7	26.7[ab]
210	4.25	15.3[bc]	31.6	60.3	12.9	25.4[b]
280	4.78	11.8[c]	36.5	53.9	13.2	21.7[b]
l.s.d.	-	3.84	-	-	-	5.39

¶Means within columns followed by a common letter are not significantly different at P=0.05

† $(Y_f - Y_c)/F$ ‡ $100 \times (N_f - N_c)/F$ § $(Y_f - Y_c)/(N_f - N_c)$

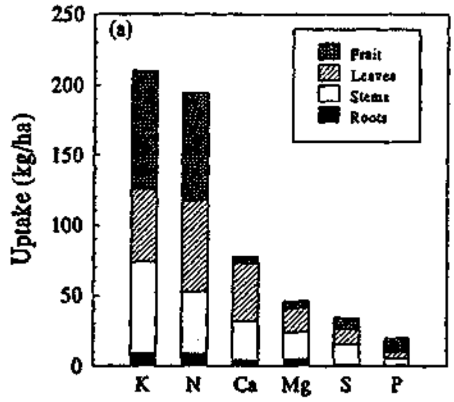
where Y_f = fruit dry weight of fertilised crop (kg/ha)

Y_c = fruit dry weight of unfertilised crop (kg/ha)

N_f = total N contained in fertilised plants (kg/ha)

N_c = total N contained in unfertilised plants (kg/ha)

F = amount of fertiliser N applied



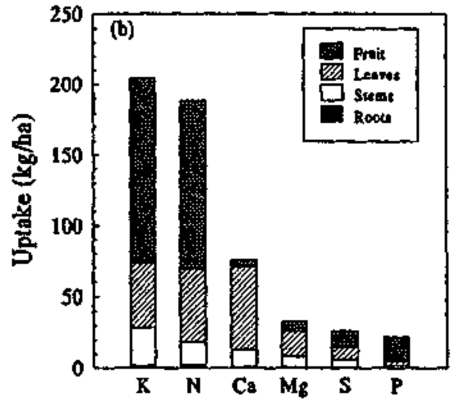


FIGURE 5. Bell Pepper Uptake of Various Elements into Plant Parts at N_{280} for (a) Spring 1990 and (b) Autumn 1991 Crops.

(Fig. 4). For N_0, a greater amount of N was absorbed from the soil in spring than in autumn.

Total plant uptake of N, P, K, Ca, Mg, and S increased with applied N. Total uptake (kg/ha) of various elements corresponding with maximum total yield (N_{280}) were ranked as follows: K (210) > N(195) > Ca (78) > Mg (46) > S (34) > P (20) for spring, and K (205) > N (189) > Ca (76) > Mg (34) > S (27) > P (22) for autumn (Fig. 5). Fruit accumulation of K, N, and P as a percentage of lime or dolomite (216-N, 85-P, 218-K, 47-S, 11-Ca, 0-Mg; J. Hall, 1991, personal communication), and the amounts absorbed at an equivalent N rate (N_{210}) by the spring and autumn crops in the present study (159-N, 17-P, 186-K, 28-S, 64-Ca, 39-Mg, and 164-N, 20-P, 194-K, 23-S, 66-Ca, and 30-Mg, respectively) enabled generalised nutrient balances to be determined (Fig. 6). Positive balances were attained for P, N, K, and S in both seasons. Values for Ca and Mg were negative indicating nett losses from the soil.

DISCUSSION

The significant response of all plant parts to increasing N and the linear relationship between absorbed N and total dry weight demonstrated the high demand of bell pepper for this element. Maximum fresh weight of marketable fruit corresponded with N_{210} to N_{280} (35.6 to 37.5 t/ha and 41.2 to 42.9 t/ha for spring and autumn, respectively). Nitrogen recommendations of approximately 225 kg/ha have been made by other workers (Hochmuth et al., 1987; Locascio and Fiskell, 1977). Crespo-Ruiz et al. (1988) reported a commercial yield of 51.2 t/ha for bell pepper fertilised with 300 kgN/ha grown with plastic mulch and trickle irrigation. leaves were the most responsive plant part to N application as the difference in leaf dry weight between N_{210} and N_{280} was significant in both seasons. The significant response of roots to N is consistent with the findings of Leskovar et al. (1989).

The generally lower agronomic efficiency values in spring than in autumn indicate a lower efficiency in fruit production from applied N in spring. These data may reflect a delayed onset of fruiting and associated reduction of fruit yield potential in spring due to the damaging effects of strong seasonal wind gusts. Despite the comparatively lower fruit production in spring than in autumn, total plant uptakes of the various nutrients were approximately equal in both seasons at N_{280}.

The difference between applied and absorbed N became progressively larger with increasing applications above N_{140}. Conversely, for applications less than N140, this nutrient was supplied by soil reserves. low levels of residual soil NO_3-N (0 to 15 cm layer) following the autumn trial (2 to 3.8 mg NO_3-N/kg, irrespective of N treatment) were well below the recommended levels during growth of Batal and Smittle (1981) of 10 to 20 mg NO_3-N/kg in spring and 15 to those for N_{70} in the present study (104-N, 13-P, 147-K, 52-Ca, and 30-Mg in spring; 88-N, 14-P, 124-K, 41-Ca, and 20-Mg in autumn).

District standard rates of P, N, K, and S application exceeded the amounts absorbed by the highest yielding treatment in the present study. The fate of these surplus elements may include immobilisation by structural incorporation into soil organic matter, adsorption in exchangeable form to soil colloids or organic matter, accumulation in the soil in an inorganic form, and/or leaching from the root zone. Much of the inorganic N in agricultural soils occurs as NO_3 (Bergstrom and Brink, 1986), and it is likely that NO_3 movement by leaching would be unrestricted in either Tropeptic Eutrustox or Ultisol soils.

The importance of marketable yield as a determinant of economic outcome and the comparatively low cost of fertilisers which contain N (6 to 7% of the total variable costs in growing the crop) are factors which are likely to restrict any impetus for decreasing N usage in the Bundaberg district (G.D. Fullelove, 1992, personal communication).

CONCLUSIONS

The high N demand of pepper was confirmed. The existing rate of N recommended for Bundaberg pepper crops (approximately 220 kg/ha) is not excessive in terms of securing maximum harvested yield as highest yields in the present study were attained at approximately N_{210} to N_{280}. However, 46 to 91 kg/ha of applied N was not recovered in the crop at these rates. The fate of this non-recovered N is not known, but the potential exists for it to be either leached down the soil profile and contribute to pollution of the groundwater, or be denitrified and lost to the atmosphere. Further work involving enriched ^{15}N under this intensive production system is required for a more complete understanding of the processes involved. Pepper producers are unlikely to reduce N inputs (in the absence of environmental protection legislation) because the value of lost production would be far greater than the saving in fertiliser cost.

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Appendix B

Manuscript for Plant and Soil

Number of text pages: 20

Number of tables: 2

Number of figures: 3

Title: Petiole sap nitrate better than total N in dried leaf as an indicator of N status of bell pepper in subtropical Australia

Short running title: Sap best indicator of N status in bell pepper

Date of most recent draft: 14 April 1993

Corresponding author details: Jason K Olsen

Bundaberg Research Station

MS 108 Ashfield Road

Bundaberg Queensland **4670**

Australia

FAX: (071) 556 129 **Phone:** (071) 556 244

Petiole sap nitrate better than total N in dried leaf as an indicator of N status of bell pepper in subtropical Australia

Jason K Olsen[A] and David J Lyons[B]

A *QDPI Research Station, MS 108 Ashfield Road, Bundaberg, Qld 4670, Australia.*

B *QDPI Agricultural Research Laboratories, Meiers Road, Indooroopilly, Qld 4068, Australia.*

Key words: Capsicum annuum L, optimum N range, petiole sap nitrate, total N

Abstract

This study was conducted to assess the usefulness of both petiole sap nitrate and total N in dried leaf in determining N status and yield potential of bell pepper (*Capsicum annuum* L.) grown with plastic mulch and trickle irrigation in subtropical Australia. Five rates of N (N_0, N_{70}, N_{140}, N_{210}, N_{280}) were applied in factorial combination with two K rates (K_0, K_{200}) (subscript in kg ha^{-1}) in randomised block experiments to cultivar 'Bell Tower' bell pepper grown at

Bundaberg Research Station in spring and autumn seasons. Optimum ranges for nitrate concentration in petiole sap and for total N in dried youngest mature leaf blades plus petioles were derived at different stages during crop development (bud development BD, first anthesis FA, 80% flowering F, and fruit set FS). Sap nitrate was approximately five times more sensitive to changes in N application than total N. Quadratic square root relationships between marketable fruit yield and petiole sap nitrate were closer and more useful than linear relationships between marketable fruit yield and dried leaf total N. Comparison of these relationships with the yield response to N addition (yield plateaux attained at highest N rates, N_{210} and N_{280}, in association with the highest sap nitrate concentrations) indicated that sap nitrate concentration was a more reliable and consistent indicator of yield potential than total N in dried leaves. For a commonly used fertiliser application strategy (60% of N applied pre-fruit set and 40% after), sap nitrate concentrations associated with 95 and 100% of maximum marketable fruit yield increased from BD (5010 to 6000 mg L^{-1} spring, 4980 to 5280 mg L^{-1} autumn) to FA (6220 to 7065 mg L^{-1} spring, 5550 to 6000 mg L^{-1} autumn). The range progressively decreased after FA to 1640 to 2800 mg L^{-1} and

520 to 1220 mg L^{-1} at FS, for spring and autumn, respectively. It was concluded that sap nitrate was a better indicator of plant N status and yield potential than dried leaf total N for bell pepper in subtropical Australia. A desirable petiole sap K concentration of greater than 4800 mg L^{-1} was proposed by correlating sap K with yield responses.

Abbreviations: BD, bud development; F, flowering; FA, first anthesis; FS, fruit set; ONR, optimum nitrogen range; YMB+P, youngest mature leaf blade plus petiole

Introduction

Analysis of plant tissues, such as the youngest mature leaf blade, has traditionally been used as a management tool for monitoring and evaluating the nutrient status of crops (Reuter and Robinson 1986). Development of methods for the rapid analysis of sap and their assessment for use either in the laboratory or on-farm has recently highlighted the benefits of the sap test over dried leaf analysis (Lyons and

Barnes 1987). Potential for using sap nitrate as a sensitive guide to the N status of several short-duration vegetable crops has been suggested for brussels sprouts (Scaife and Turner 1987), potato (Williams and Maier 1990), tomato (Gomez-Lepe and Ulrich 1974; Prasad and Spiers 1985) and corn (Jemison and Fox 1988). Few studies have directly compared sap with dried plant tissue analysis as indicators of yield potential and nutrient status of a crop.

A theoretical critical nutrient concentration exists within the plant at which yield is a predetermined proportion (usually 95%) of maximum yield (Smith 1986). For practical reasons, however, Dow and Roberts (1982) proposed a 'critical nutrient range' of concentrations above which the crop is amply supplied and below which the crop is deficient. The consequences of sub-optimal N rates are low yields and reduced profits, whereas supra-optimal applications may cause salt injury to the plants (Locascio et al. 1981), and the increased risk of environmental pollution by leaching of nitrate into groundwater (Bouwer 1987, Sharma 1991).

Methods are available for the quick correction of nutrient deficiencies in short-duration vegetable crops grown with plastic mulch by injecting soluble fertiliser directly into the root zone (e.g. fertigation, injection wheel). When combined with rapid plant analysis, these methods allow nutrient applications to closely match the nutritional requirements of the crop with the possibility of maximising yield and increasing nutrient recovery. Bell pepper (*Capsicum annuum* L) grown with plastic mulch take up less than 10 kg N ha^{-1} during the first 4 to 5 weeks after transplanting (Locascio et al. 1985) and split fertiliser applications increase N recovery over one basal rate (Russo 1991). For bell pepper grown with plastic mulch and trickle irrigation in the Bundaberg district of subtropical Australia, Olsen et al. (1993) reported that district average rates of P, N, K, and S application exceeded uptake by plants by 68 and 65 kg P, 57 and 52 kg N, 32 and 24 kg K, 19 and 24 kg S, for spring and autumn seasons, respectively.

The major objective of this study was to evaluate the effectiveness of both petiole sap and dried leaf analysis for determining the N status and associated yield of bell pepper grown with plastic mulch in subtropical Australia. Optimum N ranges were determined for both sap and dried leaf tissue at specific phenological stages during crop development.

Materials and methods

Two experiments were conducted on a Tropeptic Eutrustox (pH 7.0 to 7.1) during spring 1990 and autumn 1991 at Bundaberg Research Station (24°51′S., 152°24′E.), Queensland, Australia. 'Bell Tower' pepper seedlings were transplanted into the field in spring on 27/9/90 (age 9 weeks) and in autumn on 12/3/91 (age 7 weeks) in 80-plant datum plots arranged in a randomised, complete block design incorporating five N treatments (0, 70, 140, 210, and 280 kg/ha), two K treatments (0 and 200 kg/ha), and four blocks. Plots were 15 m long and 1.5 m wide. Sixty percent of all the N and K was applied in weekly fertigations prior to fruit set (average fruit diameter 20 mm), whereas the remaining 40% was supplied in four applications between fruit set and harvest. This strategy of fertiliser application is commonly used by commercial producers of bell pepper in the Bundaberg district. Descriptions of soil chemical properties prior to planting, field design and layout, treatment application, and agronomic practices are given in a previous study (Olsen et al. 1993) which shared common resources with the present work.

Diagnostic leaves were randomly sampled from one randomly selected half of each plot at four phenological stages (bud development, BD; first anthesis, FA; 80% flowering, F; fruit set when average fruit diameter was 20 mm, FS). These phenological stages were approximately one week apart for both spring (25 October, 1, 9, and 15 November 1990, respectively) and autumn (4, 11, 18, and 24 April 1991, respectively) seasons. In each season, the two youngest mature leaf blades plus petioles (YMB+P) per plant were removed at each sampling time from this sub-plot between 7am and 10am (when leaf material was turgid). Sampled material was immediately placed in labelled plastic bags, sealed and stored in an insulated box with cooling blocks until transportation to the laboratory where samples were held at 4°C prior to preparation. Forty YMB+P of each sample were used for sap analysis. Petioles were excised, sliced into 5 mm pieces to promote sap expression, and crushed in a stainless steel garlic crusher (pore size 1 to 2 mm). Approximately 2 mL of sap were collected, immediately frozen and stored prior to chemical analysis. Nitrate in diluted sap (1:200) was determined using an automated colorimetric method (Spann and Lyons 1985), whereas K in

1:20 diluted sap was determined by Inductively Coupled Plasma Emission Spectrometry. As the colour standards of commercially available rapid tests are shown as mg L^{-1} nitrate rather than nitrate-N, the former measure is used in the present study to express petiole sap concentrations. The remaining YMB+P in each sample were washed with deionised water, dried at 60°C, and ground through 1 mm mesh with a stainless steel mill. Samples were dried again at 105°C before chemical analysis. Nitrogen was determined by automated colorimetry (O'Neill and Webb, 1970), whereas K was determined using X-ray fluorescence spectrometry.

Fruit was harvested from the remaining half of each plot on five occasions, graded and weighed. Fresh weight of marketable fruit was recorded over five harvests in each season (12, 19, 23 December 1990, and 2, 9 January 1991 for spring; 6, 13, 27 June 1991, and 8, 19 July 1991 for autumn). Coloured fruit were harvested and considered marketable if >80 g and free from blemishes, deformation and insect damage. Yield measurements from each harvest were added together to give total yield values.

Analysis of variance was used to test the effects of treatments; treatment means were compared using the protected LSD procedure operating at 5% level of significance.

For N treatments in combination with the highest K rate (K_{200}), various models (first and second order models using the method of least squares, Mitscherlich and Cate-Nelson models - Rayment 1985) were used to investigate the relationships between total marketable fruit yield and petiole sap nitrate concentration and total marketable fruit yield and dried leaf total N concentration at each sampling time. Twenty points, arising from individual field plots (five N treatments by four blocks), were available for the regression analysis. As growth must not be limited by factors other than supply of the nutrient being studied when deriving critical nutrient concentrations (Smith 1986), data for K_0 were omitted from this analysis so that N was the only factor affecting yield. The best fitting models were used to determine the nitrate and total N concentrations at 95 and 100% (C_{95} and C_{100}, respectively) of maximum marketable yield (Y_{max}) for each season. Where Y_{max} was not easily defined (e.g. for linear functions or curved functions for which plateaux were not attained), C_{95} and C_{100} were calculated for the highest yield. These concentrations may be regarded as low approximations of the 'true' values had plateaux been attained. For either petiole sap nitrate or dried leaf total N concentrations, the range in concentrations between the C_{95} and C_{100} values at a given sampling time was used to define the optimum N range (ONR). Above this range, the crop had an ample N supply whereas below the crop was deficient (Dow and Roberts 1982).

Desirable K concentrations in petiole sap were subjectively determined by identifying those K concentrations (in combination with N rates which were deemed adequate for optimum yield; viz. N_{210}, N_{280}) at which no yield response was measured.

Results and discussion

Fruit response to N

Fresh weight of marketable fruit, average fruit weight, and marketable fruit weight as a proportion of the total weight, significantly increased ($P<0.05$) with applied N in association with the highest K rate (K_{200}) in both seasons (Table 1). For all three categories, the difference between N_{210} and N_{280} was not significant in either season indicating that sufficient N was applied to attain yield plateaux in this range of application. These data concur with an optimum N rate (224 kg/ha) reported by other scientists working with bell pepper grown with polyethylene mulch (Locascio and Fiskell 1977, Locascio et al. 1981). Nitrogen rates used by Florida growers (using seep irrigation and one basal application of fertiliser prior to planting) often exceed 340 kg/ha (Hochmuth et al. 1987). Average N rates used by pepper growers in the Bundaberg district (220 kg ha^{-1}), using trickle irrigation, raised beds, and a combination of basal fertiliser and fertigation, fall within the N_{210} to N_{280} range. Such practices result in pepper yields of 20 to 45 t ha^{-1}, depending primarily on season and disease incidence (Fullelove G D 1993 personal communication).

Petiole sap nitrate and dried leaf total N responses to applied N

Nitrogen treatment significantly increased petiole sap nitrate and dried leaf total

N concentrations at each of the four stages of development (Fig. 1). The detection of a wide range of sap nitrate and dried leaf total N concentrations as early as BD (28 or 23 days after transplanting for spring or autumn, respectively, Fig. 1a) occurred despite the fact that only 30% of the total N rate was applied at this stage of development. Detection of deficiencies as early as possible is necessary to allow sufficient time for effective remedial action and to decrease the risk of reduced yield potential.

For the majority of sampling times in both spring and autumn, petiole sap nitrate was significantly higher ($P<0.05$) for N_{210} and N_{280} than for lower N treatments (Fig. 1). In both seasons, nitrate concentration increased from BD to FA, but declined with later sampling times. Dried leaf total N concentration was less sensitive to changes in N application with no difference ($P>0.05$) among N_{70}, N_{140}, N_{210}, and N_{280} in three of four sampling times in spring (Fig. 1) and no difference ($P>0.05$) among N_{140}, N_{210}, and N_{280} in two of four sampling times in autumn (Fig. 1). Total N concentrations tended to remain constant or decline slightly with sampling time. Averaged over sampling times and seasons (except for FS in autumn when sap nitrate was 0 mg L^{-1} at N_0), petiole sap nitrate at N_{280}

was 8.0 times higher than at N_0. Conversely, dried leaf total N concentration at N_{280} was only 1.5 times higher than the N_0 treatment. The greater responsiveness of sap nitrate to N addition than that which occurred for dried leaf total N concentration indicated that sap nitrate was a more sensitive indicator of plant N status.

Rapid changes in sap nitrate from one growth stage to another indicate the importance of defining and sampling at the correct growth stage for proper interpretation. Dow and Roberts (1982) reported rapid changes in nutrient (nitrate -N, P, K, Zn) concentrations in potato petioles within a one month period and emphasised the importance of defining the stage of growth at sampling for accurate interpretation from predetermined 'critical nutrient ranges'. They stated that the use of calendar date or days after planting should be avoided as a phenologically defined growth stage gives more accurate results due to variation in rate of phenological development with season.

Sap nitrate concentration primarily reflects the amount of nitrate in the transpiration stream and to some degree that translocated from N sources within the plant. Consequently, sap reflects the N supply available to the plant at the time of sampling, and considerable variation is possible if a constant N supply is not available. Dried leaf tissue N comprises predominantly protein and remains relatively stable in short periods of N deficiency. Under conditions of temporary N depletion in the soil, a plant may have low concentrations of sap nitrate but show adequate concentrations of N in the leaves. Given that methods are available for injection of soluble fertilisers directly to the root zone to quickly ameliorate nutrient deficiencies (e.g. fertigation, injection wheel), sap nitrate appears to be a better indicator of plant N status than dried leaf total N for short duration vegetable crops.

Derivation of optimum ranges

Square root quadratic relationships between marketable yield and petiole sap nitrate (Table 2) showed that, for the majority of sampling times, yield plateaux were attained at high sap concentrations. N_{210} to N_{280} were shown to produce yield plateaux (Table 1). Linear relationships between marketable yield and dried leaf total N concentration indicated that yield plateaux were not attained with the range of dried leaf total N concentrations encountered. Therefore, N determined on oven dry tissue appears to have less value than sap nitrate in reflecting N status and yield potential of bell pepper grown with plastic mulch and trickle irrigation.

For both seasons, sap nitrate concentrations for 95 and 100% of maximum marketable fruit yield (C_{95} and C_{100}, respectively) increased from BD to FA, but declined from FA to FS (Table 2).

In the spring, ONR increased from 5010 to 6000 mg L^{-1} nitrate at BD to 6220 to 7065 mg L^{-1} at FA, whereas this range increased from 4980 to 5280 at BD to 5550 to 6000 at FA in the autumn season (Fig. 2). The range progressively decreased after FA to 1640 to 2800 mg L^{-1} at FS in spring and 520 to 1220 mg L^{-1} in autumn (Fig. 2). The relatively sudden decline in sap nitrate from FA to FS may relate to: (1) the shortfall in available soil N supply due to a high demand and usage by the plant at these development stages; (2) a higher rate of demand by sinks in the plant than the rate of uptake from the soil; (3) increasing water uptake and loss (and hence dilution of sap nitrate) associated with increasing leaf area of the plant (assuming N uptake rate is not passive and not positively correlated with transpiration water flow); (4) metabolic and/or hormonal effects.

The cultivar 'Bell Tower' is generally a prolific bearer of fruit over a relatively short harvest duration with an associated high demand for N from FS onwards. For cultivars which set fruit over a relatively longer period (with associated longer harvest duration), the demand for N from FS may not be as high. For such cultivars, the rate of decline in sap nitrate from F to FS may not be as large. Alternatively, cultivars with a relatively longer harvest duration than 'Bell Tower' would continue to produce leaves to a greater extent after fruit set. This leaf production may be associated with increased transpiration and dilution of nitrate in petiole sap.

Petiole sap ONR's have been reported for other crops. Williams and Maier (1990) reported values of 6070 to 6380 mg L^{-1} for potatoes when the length of the longest tuber was <2 mm to 2350 to 3680 mg L^{-1} when tubers were a maximum length of 50 mm. For field-grown tomatoes, Coltman (1987) suggested a critical range of 2290 to 3250 mg L^{-1} nitrate in the sap of recently matured leaves at flowering. A desirable range of 3900 to 5225 mg L^{-1} at 6 weeks from transplanting (when the tomato plants had some flowers but no fruit) was reported by Prasad and Spiers (1985). Lyons et al. (1991) reported desirable levels of petiole sap nitrate over time for kenaf (7800 mg L^{-1} during early growth to 1500 mg L^{-1} at maturity) and ONR's (from 4000 mg L^{-1} at early tillering to 2750 mg L^{-1} at late tillering) have been established for wheat and barley (Papastylianou 1989; Elliot et al. 1987).

For total N in the dried leaf, C_{95} and C_{100} values were estimated due to the linear relationship between marketable yield and N concentration (Table 2). The ONR declined with sampling time in autumn, whereas in spring, it increased from BD to FA, but declined with later sampling times (Table 2). Dried leaf total N concentrations corresponding to C_{95} (5.44 to 6.86%) were well in excess of suggested critical levels in recently matured leaves of 'Yolo Wonder' bell pepper grown in Texas (4% at initiation of flowering, Thomas and Heilman 1964) and Florida (>4%, Locascio and Fiskell 1977). Thomas and Heilman (1964) suggested that to maintain leaf tissue N concentration above 4% after flower initiation, the concentration at this phenological stage should be approximately 5%.

The ONR for petiole sap was more consistent between seasons and useful in practical terms than the ONR for dried leaf (Table 2). These data provide further evidence for the preferred use of sap analysis as a diagnostic tool. The ONR for petiole sap over spring and autumn with suggested rates of N application to increase sap levels to the desirable range (based on data presented in Fig. 1 in association with rates of applied N at each phenological stage) are presented in Fig. 2.

Response to K

The main effect of K addition on marketable yield was not significant ($P>0.05$) in spring whereas a significant response ($P<0.05$) to K addition occurred in autumn (data not presented). Petiole sap K concentrations at K_0 and K_{200} were not significantly different ($P>0.05$) at FS in spring, and the lowest K concentrations encountered over all four sampling times (in association with non-limiting N rates - N_{210}, N_{280}) were approximately 4800 mg L^{-1} (Fig. 3a). Sap K concentrations in autumn were significantly higher ($P<0.05$) for K_{200} than K_0 at all sampling times and most sap K concentrations associated with K_0 were below 4800 mg L^{-1}

(Fig. 3b). Given that a yield response to K addition occurred in autumn but not in spring, a desirable petiole sap K concentration of greater than 4800 mg L^{-1} is proposed.

Conclusions

This study demonstrated that petiole sap nitrate was more sensitive to changes in N application and was a better indicator of N status and yield potential than dried leaf total N for bell pepper grown in subtropical Australia. ONR's for petiole sap nitrate were derived at different phenological stages during crop development and a desirable range for sap K was determined. These ranges are a guide for growers/ consultants wishing to determine the N and K status of a crop and assess the adequacy of the fertiliser program. Determination of petiole sap nitrate and K is a relatively fast and simple procedure with the availability of rapid diagnostic tests. Nutrient deficiency may be quickly ameliorated by methods which allow injection of soluble fertiliser directly to the root zone of crops grown with plastic mulch. Suggested rates of N application (0 to >75 kg N ha^{-1}) to increase petiole sap nitrate levels to the ONR at four sampling times were derived. The cultivar grown in this study ('Bell Tower') characteristically sets fruit over a relatively short period and consequently has a high demand for N from FS to harvest. ONR's may need to be redefined for other cultivars which set fruit over a relatively longer period and have an associated longer harvest duration.

Optimum N rate may vary with numerous factors including soil type, size of crop, previous cropping history, management system, climate and season. Therefore, calibration of a diagnostic test is needed to predict bell pepper response to N and to assess the adequacy of a N fertiliser program in different circumstances.

Acknowledgements

Bundaberg Fruit and Vegetable Growers' Association and Horticultural Research and Development Corporation are thanked for their financial support. We also thank Ms M.M. Kelly for her contribution to sample collection, Dr M.N. Hunter and Dr K.J. Jackson for their assistance with the manuscript and Mr G.W. Blight for statistical advice.

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Captions to figures

Figure 1. Relationships between sap nitrate concentration for spring (□) and autumn (■) and rate of applied N and dried leaf total N concentration for spring (○) and autumn (●) and rate of applied N for bell pepper at (a) bud development, (b) first anthesis, (c) flowering, and (d) fruit set. Vertical bars represent the LSDs for the difference between any two means ($P=0.05$).

Figure 2. Diagramatic representation of the optimum petiole sap nitrate range (ONR) and rates of applied N required to increase deficient concentrations to the optimum range at four phenological stages (BD, bud development; FA, first anthesis; F, flowering; FS, fruit set) over two seasons (left and right bars for each pair are spring and autumn, respectively).

Figure 3. Relationship between K concentration in petiole sap and sampling time (BD, bud development; FA, first anthesis; F, flowering; FS, fruit set) at different rates of applied N and K for (a) spring and (b) autumn bell pepper crops. For those sampling times with a significant ($P<0.05$) N by K interaction, vertical bars represent LSDs for the difference between any two means ($P=0.05$).

Table 1. Yield and quality determinations of marketable fruit at different rates of applied N in association with the highest K rate (200 kg K ha^{-1}) over two seasons.†

Season	Rate of applied N (kg ha^{-1})	Marketable yield (t ha^{-1})	Average fruit weight (g $fruit^{-1}$)	Weight of marketable fruit as a proportion of total fruit weight (%)
Spring	0	15.7[a]	140[a]	56.9[a]
	70	27.3[b]	167[b]	70.2[b]
	140	30.7[bc]	169[bc]	70.9[b]
	210	35.6[cd]	173[bc]	77.1[c]
	280	37.5[d]	178[c]	76.7[c]
LSD (P=0.05)		5.53	9.4	5.3
Autumn	0	8.20[a]	162[a]	61.9[a]
	70	26.5[b]	204[b]	89.7[b]
	140	37.7[c]	212[bc]	87.8[b]
	210	41.2[cd]	218[c]	88.0[b]
	280	42.9[d]	219[c]	85. 1[b]
LSD (P=0.05)		4.01	13.6	15.4

† Values within columns followed by common letters are not significantly different at $P<0.05$

Table 2. Equations of best fit relating marketable fruit yield (Y, kg ha^{-1}) to either petiole sap nitrate concentration (X, mg L^{-1}) or dried leaf total N concentration (X, % dry weight) for four sampling times over two seasons. Concentrations required for 95 and 100% of maximum yield (C_{95} and C_{100}, respectively) are also shown.

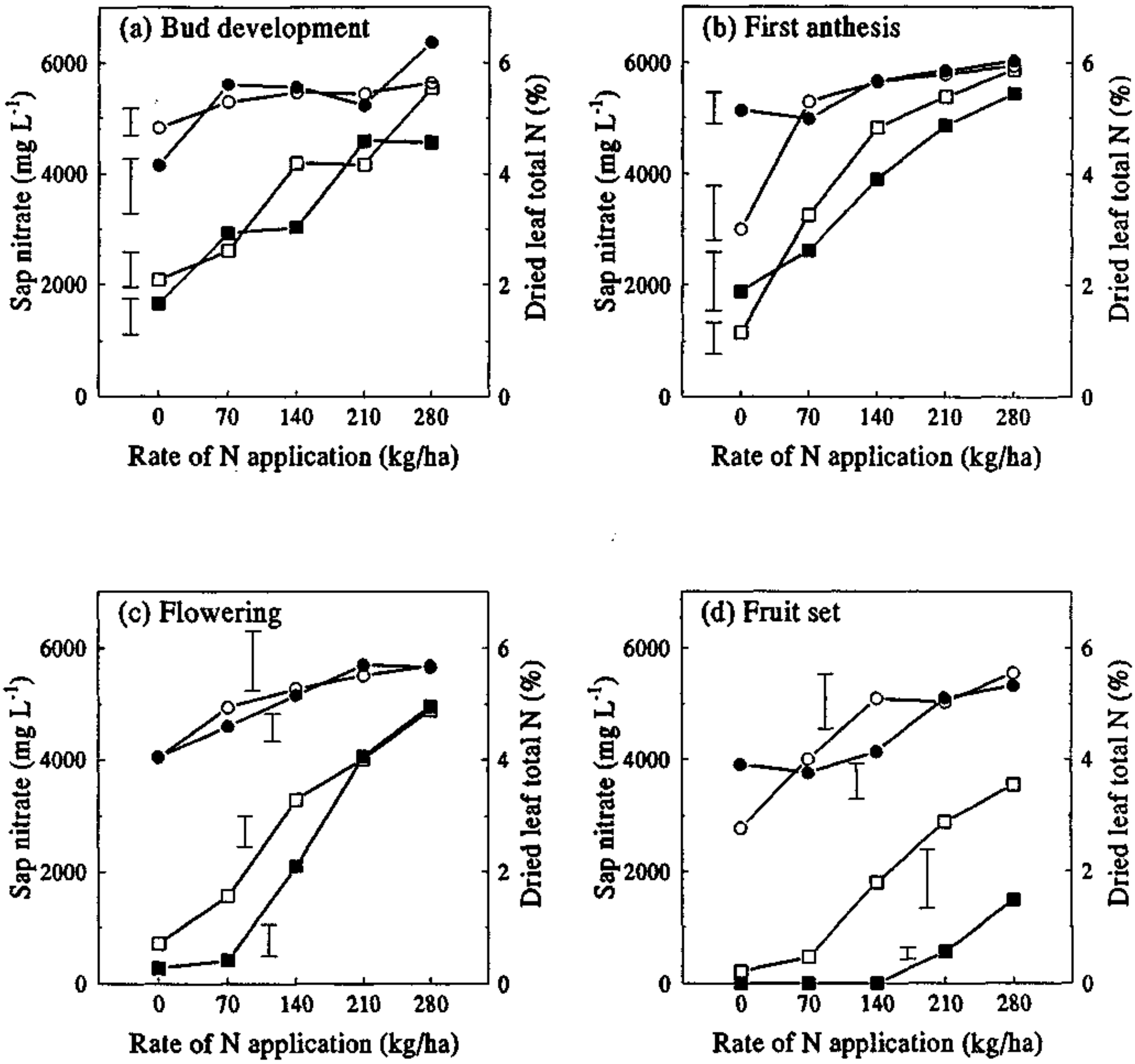
Plant component sampled†	Season	Phenolog. stage‡	Time after transpl. (days)	Equation of best fit	n	R^2	Significance of equation§	C_{95}	C_{100}
Petiole sap (Nitrate conc.)	Spring	BD	28	$Y = -46200 - 12.0X + 2000\sqrt{X}$	20	0.70	**	5010	6000
		FA	35	$Y = -3460 - 1.12X + 603\sqrt{X}$	20	0.83	**	6220	7065
		F	43	$Y = -149 - 4.20X + 816\sqrt{X}$	20	0.74	**	4620	6000
		FS	49	$Y = 7000 - 9.68X + 1060\sqrt{X}$	20	0.67	**	1640	2800
	Autumn	BD	23	$Y = -4510 - 5.35X + 314\sqrt{X}$	20	0.54	**	4980	5280
		FA	30	$Y = -28900 - 2.35X + 1160\sqrt{X}$	20	0.69	**	5550	6000
		F	37	$Y = 15100 + 1.20X + 330\sqrt{X}$	20	0.62	**	4860	5460
		FS	43	$Y = 24200 - 17.4X + 1160\sqrt{X}$	20	0.45	**	520	1220
YMB+P (Total N conc.)	Spring	BD	28	$Y = -50700 + 15000X$	20	0.42	**	5.89	6.02
		FA	35	$Y = 70.2 + 5710X$	20	0.69	**	6.53	6.87
		F	43	$Y = -7700 + 7280X$	20	0.49	**	6.19	6.46
		FS	49	$Y = 5450 + 5330X$	20	0.64	**	5.98	6.35
	Autumn	BD	23	$Y = -8460 + 7390X$	20	0.29	*	6.86	7.16
		FA	30	$Y = -61600 + 16800X$	20	0.45	**	6.28	6.40
		F	37	$Y = -46900 + 15700X$	20	0.74	**	5.76	5.94
		FS	43	$Y = -21000 + 11800X$	20	0.37	**	5.44	5.68

† YMB+P Youngest mature leaf blade plus petiole.

‡ BD, FA, F, FS Bud development, first anthesis, flowering, and fruit set, respectively.

§ *, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Olsen and Lyons Fig. 1



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OLSEN & LYONS FIG 2.

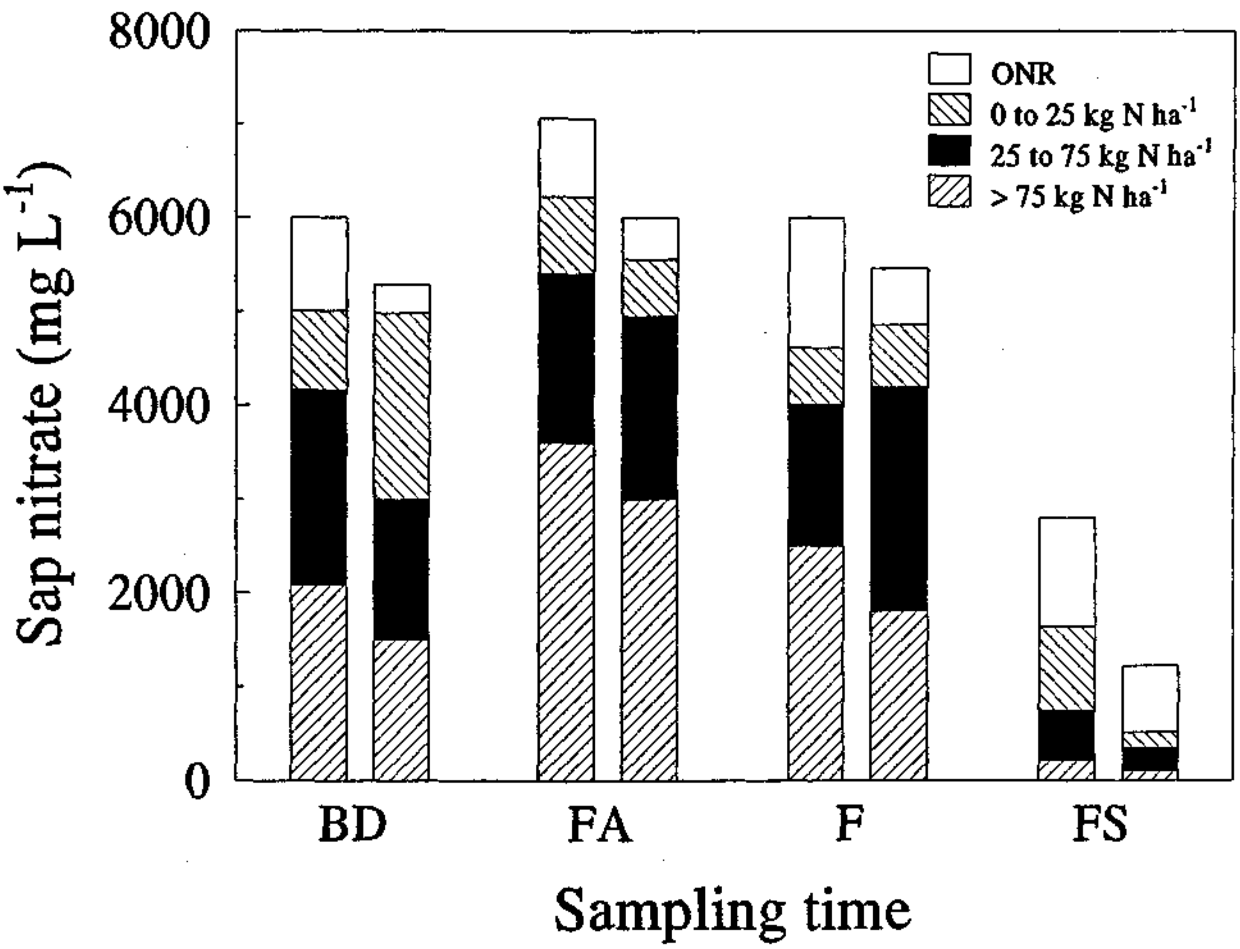

Fig. 2 Diagramatic representation of the optimum petiole sap nitrate range (ONR) and rates of applied N required to increase deficient concentrations to the optimum range at four phenological stages (BD, bud development; FA, first anthesis; F, flowering; FS, fruit set) over two seasons (left and right bars for each pair are spring and autumn, respectively).

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Olsen and Lyons Fig.3

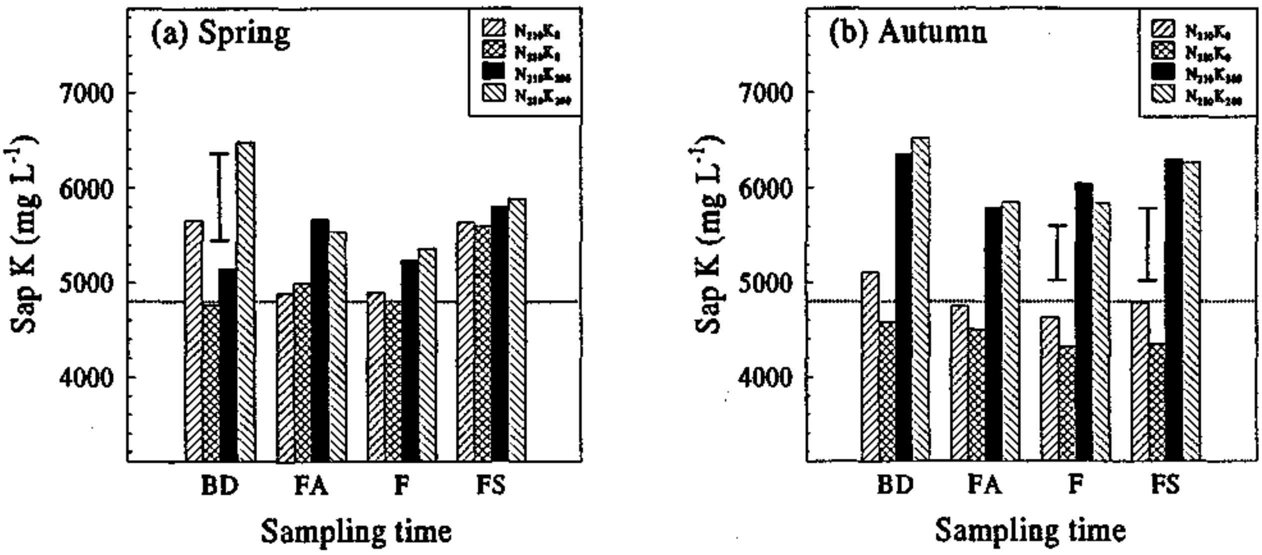

Fig. 3. Relationship between K concentration in petiole sap and sampling time (BD, bud development; FA, first anthesis; F, flowering; FS, fruit set) at different rates of applied N and K for (a) spring and (b) autumn bell pepper crops. For those sampling times with a significant ($P < 0.05$) N by K interaction, vertical bars represent LSDs for the difference between any two means ($P = 0.05$).

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Qld Fruit and Vegetable News Thurs 22 Oct 1992

Desirable levels of nitrogen and potassium in capsicum sap

By Jason Olsen, Bundaberg Research Station & David Lyons, Agricultural Chemistry, DPI.

Capsicum nutrition experiments were set up in spring 1990 and autumn 1991 at Bundaberg Research Station to define desirable levels of nitrogen and potassium in petiole sap.

Sap was expressed from petioles of the youngest mature leaves at four growth stages (bud development, early flowering, late flowering and fruit set) and analysed at Agricultural Chemistry Laboratories for nitrogen and potassium content. The following results show at what levels sap nitrogen and potassium should be maintained to achieve maximum yields.

Results

Nitrogen

As nitrogen fertiliser applications increased yields of fruit increased and levels of sap nitrate increased. We were able to establish strong correlations between yield and sap nitrate at the four growth stages sampled (bud development, early flowering, late flowering and fruit set).Consequently we are able to define levels of sap nitrate over time for optimal yield and quality, and for use in fertiliser management. Sap nitrate should not be less than 4500 mg/L at bud development, 5000 mg/L at early flowering, 4000 mg/L at late flowering and 2800 mg/L at fruit set. (See Figure 1 right.)

Potassium

Our research findings have shown that potassium levels in the sap should be maintained at approximately 5000 mg/L at all growth stages for optimal yields.

Sap Testing

Sap testing is a monitoring technique with interpretations based on trends not on one result. If a laboratory is nearby then sap analysis should be carried out by that laboratory.If no laboratory is nearby, a grower can do sap testing using commercially available tests that are suitable for farm use. The sap nitrate field test recommended by DPI is Merckoquant strips. The procedure involves taking approximately 50 leaves and expressing the petiole sap into a small container.

Sap testing is finding a place in many different crops, in this case tomatoes.

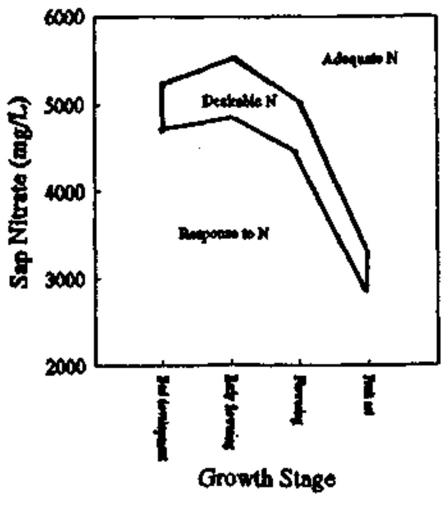


Figure 1.

Sap is expressed by chopping the petioles into small pieces and then crushing them in some fashion (eg garlic crusher). The sap is then diluted 20 times with water and the test strip dipped into the diluted sap. The test strip is removed from the sap and allowed one minute to change colour.

The colour of the test strip is then compared with a standard colour chart to determine the nutrient concentration.

Collecting samples for capsicum sap analysis.

Append. 12

Optimum planting density for capsicums - 30 000/ha autumn, 40 000/ha spring

Jason K Olsen, David Gillespie and James T Schaefer
(Bundaberg Research Station)

Number of plants per hectare (planting density) significantly effected yield of four commercially available capsicum cultivars (Target, Domino, Cordoba, Bell Tower) grown over two seasons (autumn 1990 and spring 1992) at Bundaberg Research Station. Planting densities of 30 000 plants per hectare (12 000 plants per acre) in autumn and 40 000 plants per hectare (16 000 plants per acre) in spring are recommended. Assuming you have 1.5 m between beds, this range is the same as two rows (30 cm apart) per bed with an in-row spacing of 35 cm (spring) to 45 cm (autumn) between plants. Using this method, plants within each bed should be arranged in a diamond configuration by staggering plants to maximise the distance between them.

Increasing plant number decreased marketable yield in autumn, whereas in spring, closer plant spacing increased yield to approximately 40 000 plants per hectare, but did not significantly increase yield at higher densities (Figure 1). A high planting density associated with close planting tends to cause more shading in autumn than in spring due to the northerly slant of the sun in autumn and winter. This autumn shading is also associated with entrapment of moisture in the canopy (due to low evaporation) with an associated higher incidence of diseases such as bacterial spot. Relatively higher yields in spring than in autumn at high planting densities were partly due to less shading due to the vertical position of the sun and a drier canopy (with a lower disease incidence) associated with the drying effects of longer hotter days. Regular spraying with copper hydroxide (Kocide®) for prevention of bacterial spot is important in both spring and autumn, but there is need for extra care to be taken in autumn.

Number of marketable fruit per hectare increased with planting density in spring but decreased in autumn (Figure 2). Strong winds at pollination in spring may have limited the number of fruit set, particularly for plants more widely spaced apart (and relatively unprotected at low planting densities) than those planted more closely (with more protection at high planting densities). Low numbers of fruit at high planting densities in autumn may be associated with a higher degree of shading than in spring. Despite less fruit per hectare in spring than in autumn at the 30 000 to 40 000 plants per hectare range (Figure 2), yield was approximately the same for spring and autumn at this range (Figure 1.) These similar yields reflect that average weight of marketable fruit was much heavier in spring than in autumn (Figure 3). The message here is that a few large fruit pack the same number of cartons as many small fruit. Markets prefer 30 capsicum fruit or fewer per box for quick sale. This size equates to fruit which weigh at least 200 grams each. Only the lowest planting density in the autumn trial (40 000 plants/ha) produced fruit which were heavy enough for market preference. In spring, all planting densities produced fruit which were in the desirable weight range, even the most closely planted treatment (178 000 plants per hectare, Figure 3). Lower planting densities for autumn (30 000 plants per hectare) are recommended than for spring (40 000 plants per hectare) in order to maximise production of fruit in the optimum weight category.

Production of larger, heavier fruit in spring than in autumn is also emphasised by the distribution of fruit into various weight categories at the 40 000 plants per hectare planting density (Figure 4). The majority of fruit were "medium" sized (141 to 200 grams per fruit) in autumn whereas most fruit produced in spring were in the more desirable "medium large" (201 to 260 grams per fruit) weight range (Figure 4). Many more fruit in the "large" and "extra large" categories (261 to 320 gram and >320 gram ranges, respectively) were produced in spring than in autumn.

Desirable plantings densities for capsicums are those at which the adjacent leaves of neighbouring bushes are just touching one another to form a kind of open hedge-row. Although planting densities recommended here were determined on yield data, slightly larger bushes grown in autumn (due to the warm temperatures encountered early in the crop's vegetative life) are consistent with the recommendation of fewer plants per hectare in autumn. Additionally, the importance of adequate spray penetration for disease control (e.g. bacterial spot) is especially important in the autumn, so a slightly more open canopy is desirable.

Despite the findings of recent Florida research that capsicum fruit size is unaffected by high planting densities and that plant populations in excess of 105 000 plants per hectare produced

the highest marketable yields, it is most apparent that these recommendations do not apply for fresh-market capsicum production in subtropical Australia. If high yields of good quality fruit were to be attained at such high planting densities in this environment (and they don't), consideration would need to be given to the variable cost of seed or speedlings per hectare.
Many thanks to the Bundaberg Fruit and Vegetable Growers' Association and Horticultural Research and Development Corporation who provided funds for this research and to seed companies for supplying the seed.

Captions to figures

Figure 1. Effect of planting density on yield of marketable capsicum fruit over two seasons. Yield was averaged from four cultivars (Target, Domino, Cordoba and Bell Tower).

Figure 2. Effect of planting density on number of marketable fruit per hectare over two seasons. Fruit number was averaged from four cultivars (Target, Domino, Cordoba and Bell Tower).

Figure 3. Increasing plant numbers reduced marketable capsicum fruit weight in both spring and autumn seasons. Fruit weight was averaged from four cultivars (Target, Domino, Cordoba and Bell Tower).

Figure 4. Effect of growing season on number of marketable fruit in various weight categories. Fruit number was averaged from four cultivars (Target, Domino, Cordoba and Bell Tower) grown at a commercial planting density of approximately 40 000 plants per hectare. Fruit weight categories (grams per fruit) equate to the following number of fruit per carton: $\leq$140 g/ fruit = >43 fruit/ box; 141 to 200 g/ fruit = 43 to 30 fruit/ box; 201 to 260 g/ fruit = 30 to 23 fruit/ box; 261 to 320 g/ fruit = 23 to 19 fruit/ box; >320 g/fruit = <19 fruit/box.

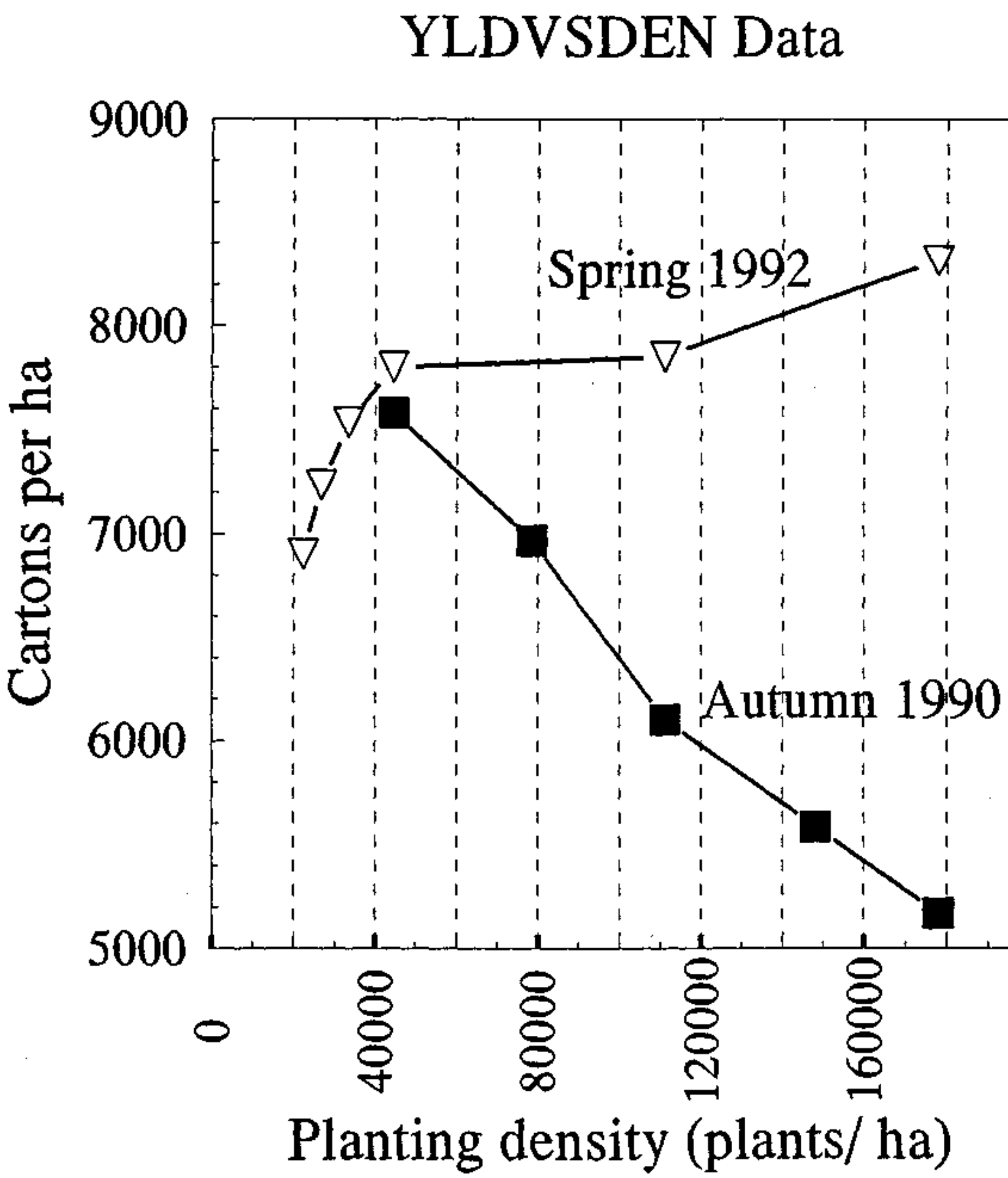
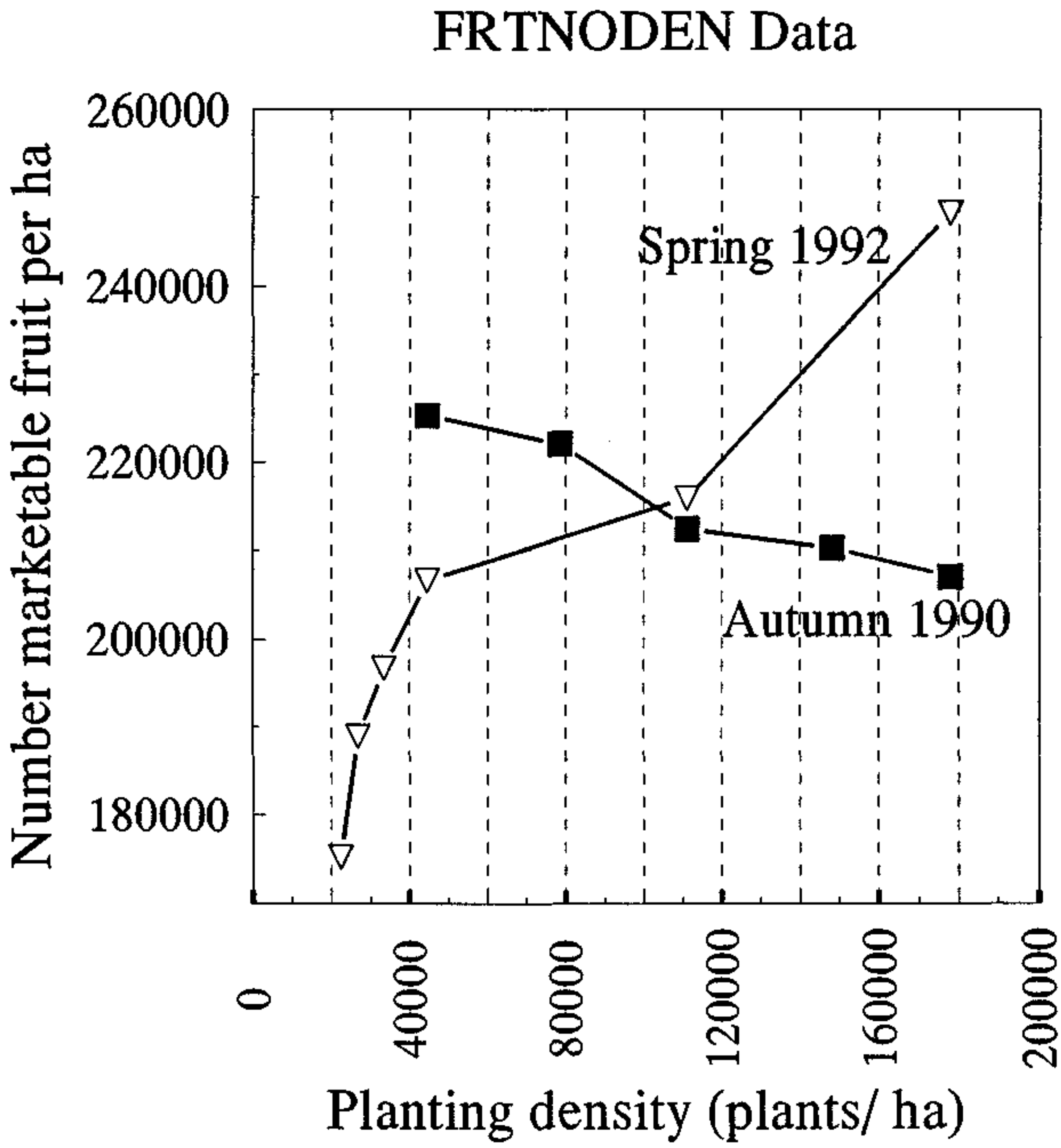


Figure 1. Effect of planting density on yield of marketable capsicum fruit over two seasons. Yield was averaged from four cultivars (Target, Domino, Cordoba and Bell Tower).



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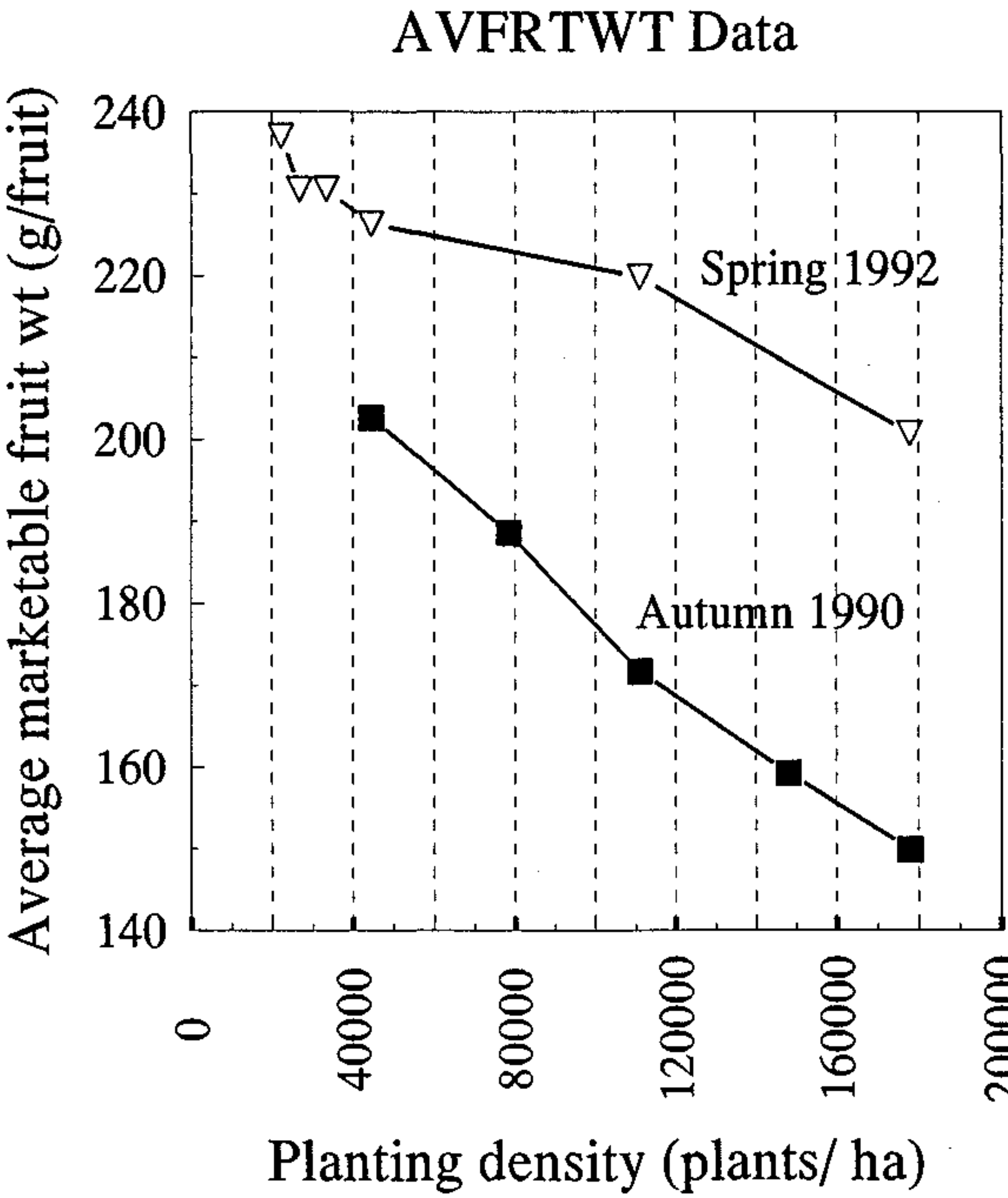

Figure 3. Increasing plant numbers reduced marketable capsicum fruit weight in both spring and autumn seasons. Fruit weight was averaged from four cultivars (Target, Domino, Cordoba and Bell Tower).

Lowest common density 44,444 /ha

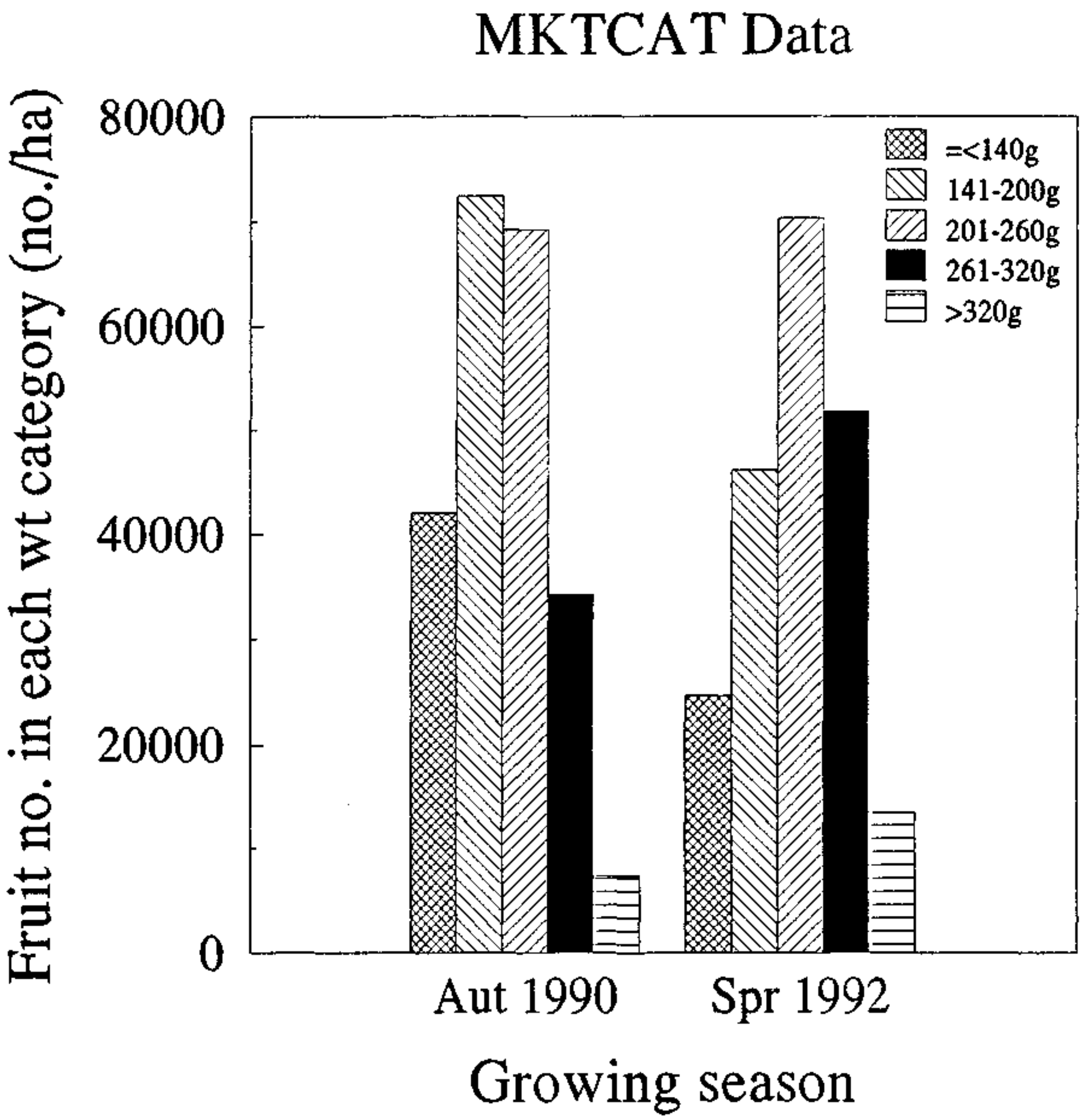

Figure 4. Effect of growing season on number of marketable fruit in various weight categories. Fruit number was averaged from four cultivars (Target, Domino, Cordoba and Bell Tower) grown at a commercial planting density of approximately 40 000 plants per hectare. Fruit weight categories (grams per fruit) equate to the following number of fruit per carton: $\leq$140 g/ fruit = >43 fruit/ box; 141 to 200 g/ fruit = 43 to 30 fruit/ box; 201 to 260 g/ fruit = 30 to 23 fruit/ box; 261 to 320 g/ fruit = 23 to 19 fruit/ box; >320 g/fruit = <19 fruit/box.

Appendix E

Which capsicum cultivars to plant in spring or autumn?

Jason K Olsen, David Gillespie and James T Schaefer
(Bundaberg Research Station)

Four capsicum cultivars (Target, Domino, Cordoba and Bell Tower) were compared over two growing seasons (autumn 1990 and spring 1992) for commercial yields at Bundaberg Research Station. At the commercial planting densities selected (30 000 to 40 000 plants per hectare), Target was the best performer in the autumn season, whereas Domino yielded most cartons in spring (Figure 1). With the exception of Domino, all cultivars produced fewer cartons in spring than in autumn. Higher autumn production was associated with a greater number of marketable fruit than in spring which may relate to poor pollination in spring due to strong winds at flowering. Out of the four cultivars, total yield of Bell Tower was consistently lower than the other cultivars over both seasons.

Total number of marketable fruit was considerably higher in autumn than in spring (refer to size of bars in Figure 2), whereas fruit were comparatively larger and heavier in spring than in autumn (refer to distribution of bars in Figure 2). As shown in Figure 1, total cartons per hectare was not much lower in spring than in autumn. The message here is that in doesn't take many large fruit (in spring) to produce the same number of boxes as many smaller fruit (in autumn). Optimum fruit size for markets is approximately 30 fruit per carton or less ("medium large" size category). Cordoba and Bell Tower consistently produced "medium" to "medium large" sized fruit (43 to 30 and 30 to 23 fruit per box categories, respectively) irrespective of season (Figure 2). "Large" to "extra large" fruit (19 to 23 and less than 19 fruit per carton, respectively) were produced to the greatest extent by Target and Domino. No cultivar consistently produced the most small fruit.

Despite the fact that Domino produced most cartons in spring 1992, this cultivar was heavily infested (1 in 5 plants affected) by potato virus Y (PVY). This viral disease causes stunting of the plant, mottled and deformed leaves and reduced yields. The virus is spread by aphid vectors (e.g. Green Peach Aphid). Incidence of PVY is reduced through control of the aphids (e.g. spray regularly with insecticides such as endosulfan, dimethoate, or, if infestation gets out of control, use methamidophos). Target, Cordoba and Bell Tower are Northrup King capsicum cultivars. Domino is produced by New World/Asgrow. Many thanks to the

Bundaberg Fruit and Vegetable Growers' Association and Horticultural Research and Development Corporation who funded this research and to the seed companies for supplying the seed.

Captions to figures

Figure 1. Cartons of marketable capsicum fruit for four cultivars grown at commercial planting densities over two seasons.

Figure 2. Number of marketable fruit in various size categories for four capsicum cultivars grown at commercial planting densities. A large number of fruit per box means small fruit and vice-versa.

Aut = 44,444 plants/ha   Spring 1992 = 33 333 plants/ha

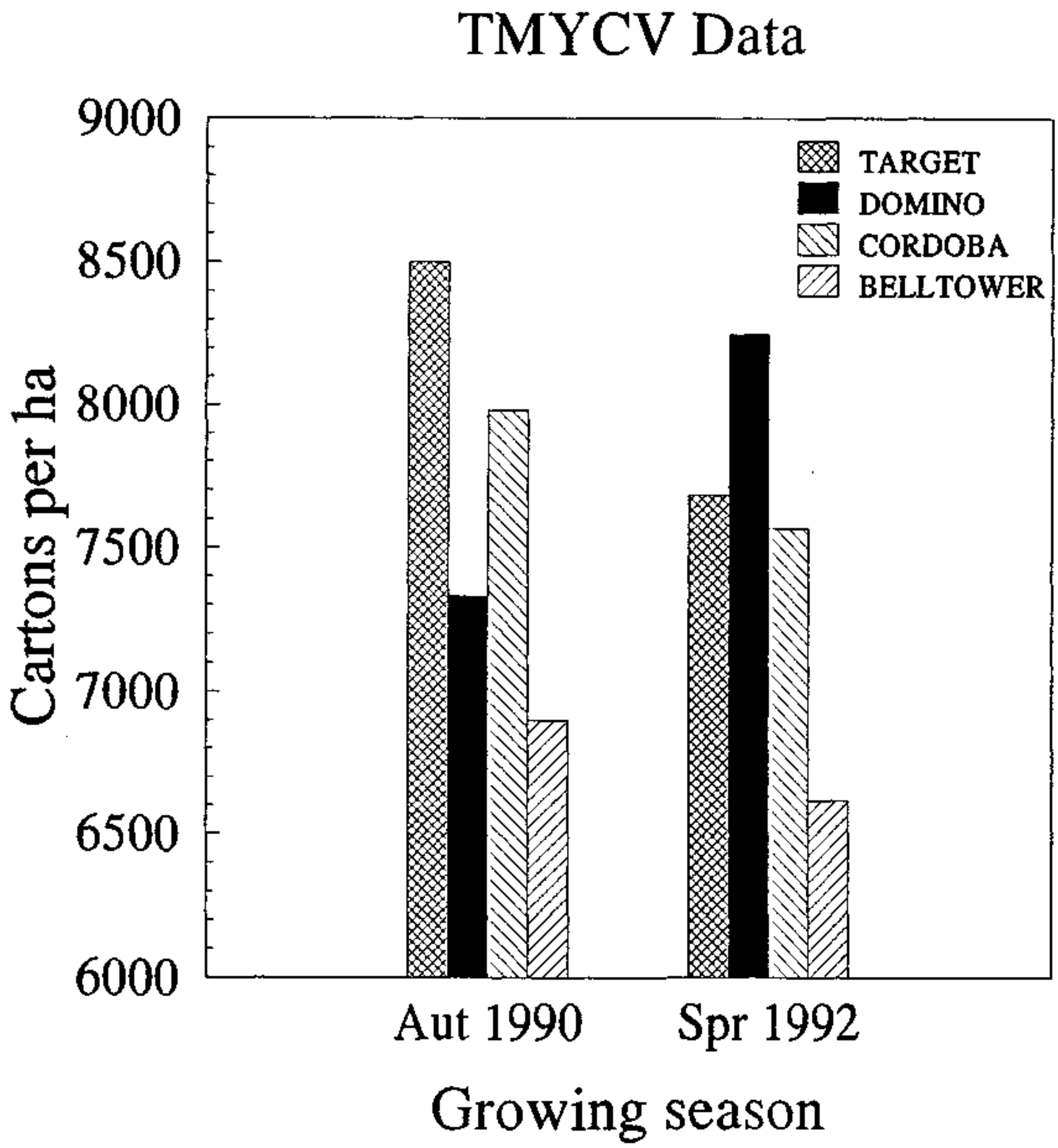

Figure 1. Cartons of marketable capsicum fruit for four cultivars grown at commercial planting densities over two seasons.

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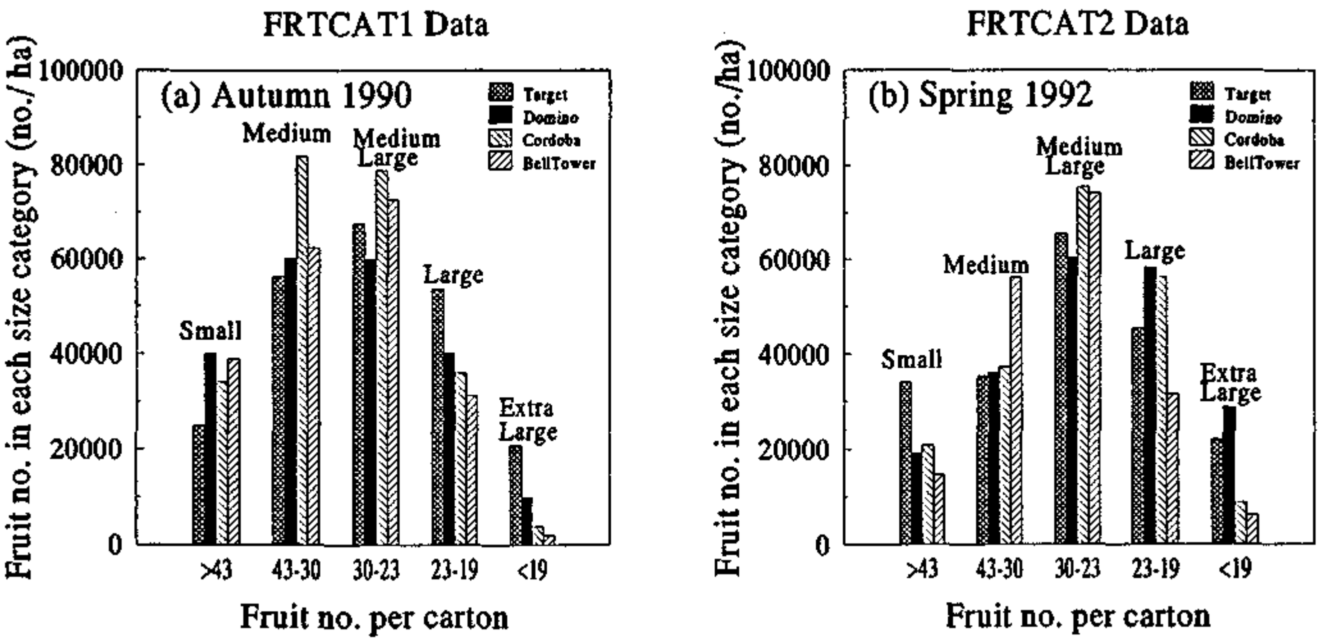

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QUEENSLAND FRUIT AND VEGETABLE NEWS
THURSDAY, 23 MAY 1992

Appendix F

LIFTOUT - TECHNICAL FEATURE

Mature capsicum collapse

By Jason Olsen, Horticulture Branch, Lynton Vawdrey, Plant Pathology Branch, David Gillespie, Horticulture Branch, Bundaberg, DPI

"Mature plant collapse" (sometimes known as "Sudden Wilt" or "Root Rot") was a widespread problem in the Bundaberg district in spring 1991, killing up to 50 per cent of capsicum plants.

Young plants are generally unaffected and the disease shows itself from fruit set onwards. Early warning signs are wilting during the warm part of the day, general yellowing of leaves and stunting.

Eventually plants completely wilt, lose their leaves and are left standing with small red fruit no bigger than golf balls (see photo below).

The occurrence of the disease usually relates to poor management practices which produce stress on the plants. For example, over-irrigating when young and under-watering when the crop is setting fruit is the most common problem.

Such practices starve the root systems of oxygen and do not allow roots to grow in search of water. Proper irrigation methods involve adequate watering following planting to wet up the sides of the beds, but only watering when necessary thereafter.

Tensiometers should be installed from bud development onwards and monitored daily to maintain the vacuum pressure between 10 and 40 centibars.

Soil should not be watered to any wetter than 10 centibars.

The most critical time for avoiding moisture stress in capsicums is from fruit set onwards.

Another poor management practice to be avoided is planting into black plastic mulch beds in the heat of summer.

Roots are literally "cooked" in the ground and become prone to infection by soil pathogens.

White or reflective plastic mulch should be used in warm times of the year.

A number of fungi are often found associated with the root rot. These include Pythium and Fusarium species.

The Pythium is considered the primary invader by causing the decay of young feeder roots.

None of these fungi are thought to be solely responsible for "mature plant collapse", but given favourable soil conditions for soil pathogens, work synergistically together to cause the disease.

Beneficial soil organisms such as vesicular arbuscular mycorrhizae (VAM) are also killed by these pathogens.

Poor capsicum crops following fumigation were once thought to be associated with residual toxicity of the fumigant, but are now more closely aligned to the demise of the symbiotic VAM.

There have been many theories as to the reason for the severity of "mature plant collapse" in Bundaberg during spring 1991.

One popular theory relates to the failure of crop residues in the soil to break down during the unusually dry season the previous year, allowing soil pathogens to over-winter in the residue.

Other suggestions include fungus gnats which are purportedly able to spread Pythium in young seedlings in the nursery. There is no scientific evidence to suggest that this is so.

A more plausible suggestion, however, is the small root systems of recently released F_1 capsicum hybrids and resultant stress during the growing period.

Such hybrids develop comparatively small root systems but are able to produce high yields.

Often the root systems are unable to cope with the requirements of water and nutrients placed on them by the shoots.

Traditional varieties such as "Green Giant" had well established root systems and were less prone to the disease.

Most capsicum cultivars are susceptible to the disease, although the cultivar "Domino" was the most tolerant in a trial conducted at Bundaberg Research Station in spring 1991 (Figure 1).

Many chemical treatments are supposed to control "mature plant collapse".

Purasoil (quintozene) drenches have been used without result as quintozene does not control the pathogens associated with the disease.

Phosphorus acid reportedly gives some control of Pythium but does not work against Fusarium. The real solution in controlling the disease is establishing a soil environment in which root growth is promoted.

Incidence of the disease from season to season is not consistent, suggesting environmental factors play an important role, and severe outbreaks seem to occur in 4 to 6 year cycles.

With the high summer rainfall in early 1992, the incidence of the disease in 1992 may not be as widespread as it was in 1991.

Capsicum bush with "mature plant collapse" in foreground. The disease usually occurs at fruit set, when the plant shifts its emphasis from root growth to fruit production.

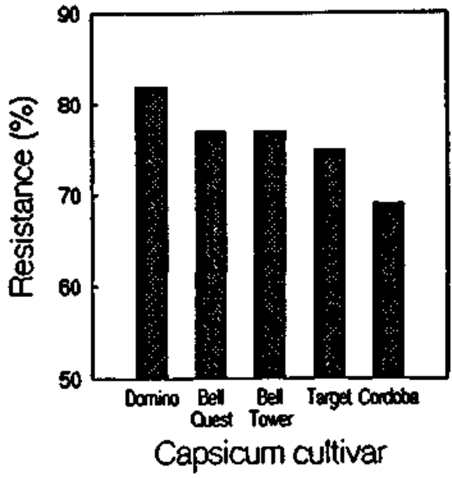
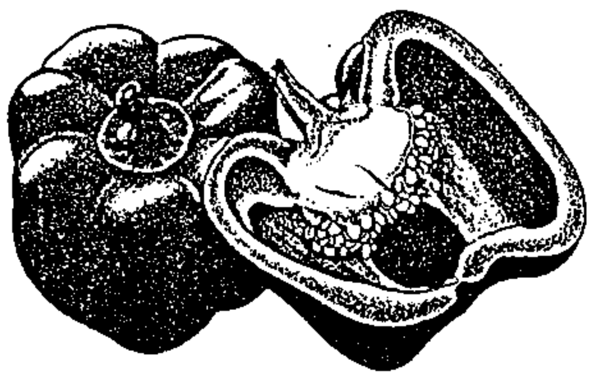


Figure 1. Resistance of capsicum cultivars to "Mature plant collapse".

Appendix 5.

UEENLSAND DEPARTMENT
OF PRIMARY INDUSTRIES

CAPSICUM FIELD DAY



50 people total
35 growers
consultants
seed reps
DPI
WIN TV.

BUNDABERG RESEARCH STATION

28 NOVEMBER 1991

CAPSICUM NUTRIENT REQUIREMENTS FOR HIGH YIELDS

A capsicum trial was set up in spring 1990 to look at the nutrient requirements of a capsicum crop growing under optimum conditions.

The following information was found from that trial:

a) Relationship between nitrogen uptake and yield

Nitrogen is vital to high capsicum yields (refer to Fig.1). The more nitrogen absorbed by the crop, the more yield increased up to approximately 200kg nitrogen/ha. Total yield and nitrogen uptake by the crop were linearly related up to this rate of absorbed nitrogen. Too much applied nitrogen can cause plants to become "leggy" and fall over causing fruit sunburn. Also, poor plant root systems and nutrient leaching may result from excessive nitrogen rates.

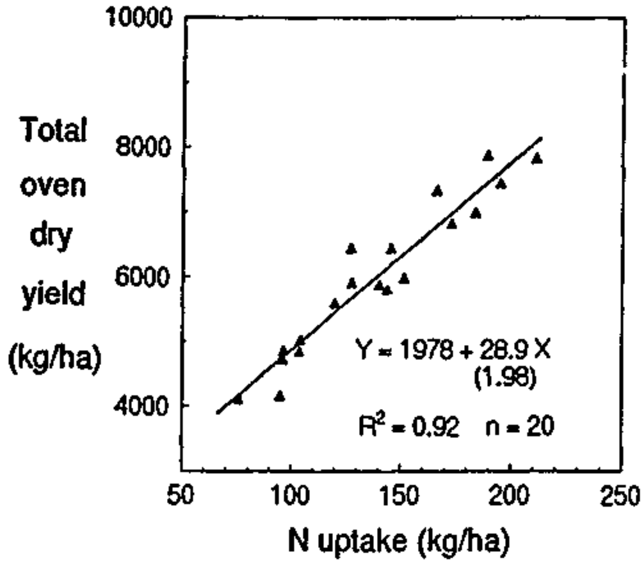


Fig. 1 Relationship between total yield and N uptake

b) Total uptake of various nutrients

The capsicum crop grown in this trial under optimum conditions took up the following amounts (kg/ha) of nutrients:

210	Potassium (K)
195	Nitrogen (N)
78	Calcium (Ca)
46	Magnesium (Mg)
34	Sulphur (S)
20	Phosphorus (P) (Refer to Fig.2)

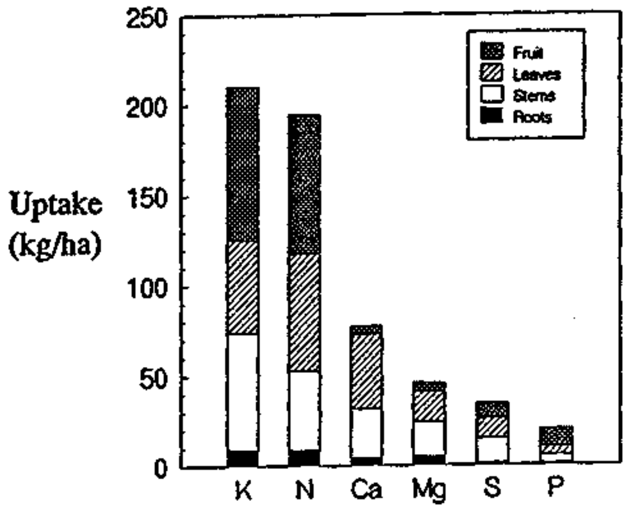


Fig. 2 Capsicum uptake of various elements at N_{280}.

These total uptake values were from the whole plant, including fruit, leaves, roots and stems.

Total uptakes of potassium and nitrogen were higher than the other nutrients. Therefore, adequate levels of these nutrients need to be applied so that supply equals demand. The high amounts of these nutrients found in the fruit show their importance to fruit development. However, nitrogen may be mobilised from other plant parts such as leaves during fruit fill.

The low amount of calcium in fruit (4kg/ha) compared with leaves (41kg/ha) indicated the importance of applying calcium (usually as calcium nitrate) when fruit are developing. Plants are unable to mobilise calcium to rapidly growing parts such as fruit, so it is important that adequate amounts of calcium are applied at this time to avoid blossom-end rot.

A relatively small quantity of phosphorus (20kg/ha) was taken up by the crop. Many growers use excessive rates of phosphorus, although some types of soil are able to fix applied phosphorus and make it unavailable to plants.

Capsicum Field Day
Sap Testing

D. Lyons/J. Olsen

Chemical analyses of dried leaf and sap were carried out in Brisbane and this talk today deals with findings from the sap work. Sap was expressed from petioles of youngest mature blades.

Nitrogen

As N applications increased yields of fruit increased and levels of sap nitrate increased. We were able to establish strong correlations between yield and sap nitrate at the four growth stages sampled (bud development, early flowering, late flowering and fruit set). Consequently we are able to define desirable levels of sap nitrate over time for optimal yield and quality, and for use in fertiliser management. Sap nitrate should not be less than 4500 mg/L at bud development, 5000 mg/L at early flowering, 4000 mg/L at late flowering and 2,800 at fruit set.

Potassium

Our research findings have shown that potassium levels in the sap should be maintained above 5000 mg K/L for optimal yields.

Sap testing is a monitoring technique with interpretations based on trends not on one result. If a laboratory is nearby then sap analysis should be carried out by that laboratory.

If this is not possible then a grower can do sap testing using commercials available tests that are suitable for farm use. The sap nitrate field test recommended by DPI uses Merckoquant strips, and this test will be demonstrated.

Capsicum Variety by Density Experiment

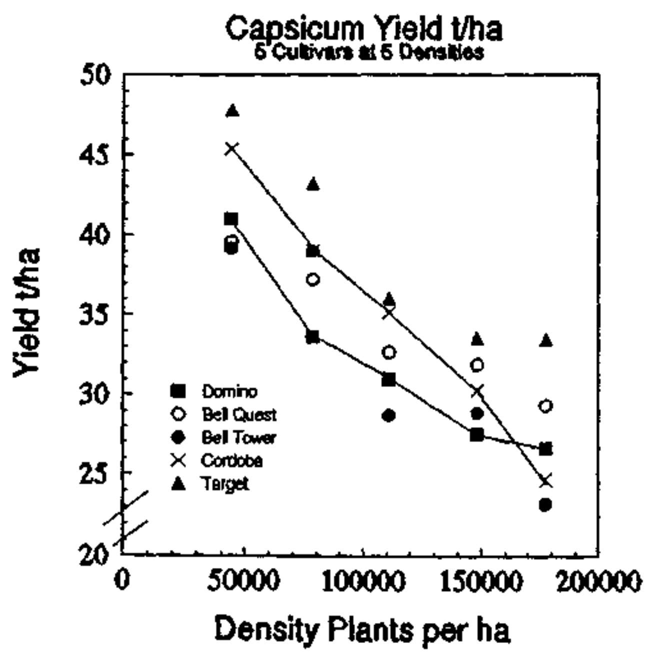
A capsicum variety by density experiment carried out at Bundaberg Research Station in autumn 1990 showed that high density planting lowered yield and fruit size.

Although the optimum planting density was not found in this trial it showed that plants planted in double rows 300mm apart should not be grown any closer than 300mm within rows.

Five commercial lines, Domino, Bell Quest, Bell Tower, Cordoba and Target were field planted in March in densities of 177,778 plant/ha, 148,148 plants/ha, 111,111 plants/ha, 78,431 plants/ha and 44,444 plants/ha. Bed centres were spaced 1.5m apart.

The highest density yielded 27.5 tonnes per hectare while the lowest density yielded 42.6 tonnes/ha. Target was the highest yielding variety over all densities, Bell Quest and Cordoba were the next best. The data in Figure 1 represents yield at each of the five densities.

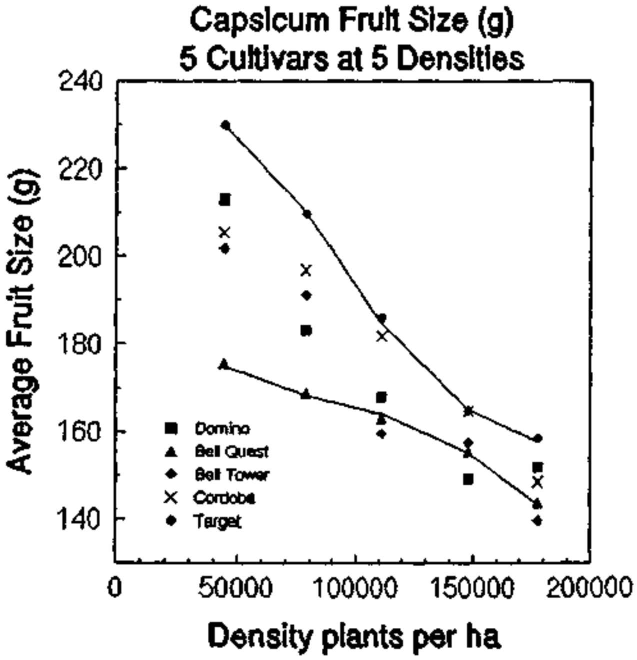
Figure 1



Average fruit size across densities was Target 189gm, Cordoba 180gm, Domino 173gm, Bell Tower 170gm, and Bell Quest 161gm.

The highest density had an average fruit size of 148gm whereas the lowest density gave an average fruit size of 205gm. The data in figure 2 represents the fruit size at each of the 5 densities.

Figure 2



These findings were in contrast to the results of similar trials in Florida, USA in recent years. Often Queensland results paralleled those of trials in Florida.

On a yield per bush basis the lowest density produced 958gm while the highest density produced only 154gm of fruit.

The higher density plantings also produced a far bigger percentage of small fruit. For example, 50.6 percent of the fruit in the highest density planting (177,773 plants/ha) was in the 80-139gm (or small fruit size) range, while only 17 percent of the fruit in the lowest density planting (44,444 plant/ha) were in this range.

Field Ripening Of Capsicums With Ethrel

Ross Wright of Bowen Horticultural Research Station has recently conducted research into the possibility of using ethephon (Ethrel ®) for field ripening of capsicum fruit. The optimum treatment from his work is presented for your convenience at this field day. This treatment is 5 litres/ha Ethrel mixed with 10kg/ha calcium hydroxide.

The following report was written by Ross for publication at this field day.

Objectives

To enhance field ripening of capsicum fruit using ethephon (Ethrel ®) for both fresh market use and the processing market.

Advantages

- Fresh market domestic prices are generally higher for red capsicums than for green or coloured (breaker to part red).
- The processing market requires all fruit to be at the full red stage and field ripening with ethephon can concentrate the maturity of crop in the field.
- It has the potential to provide greater flexibility in catering to market demands.

Disadvantages

- This treatment generally terminates further productivity or delays it for a long period, depending upon the rate of ethephon applied.
- Ethephon applications can be associated with heavy leaf loss leading to sunburn of fruit.

Preliminary Results

Results have been obtained using the cultivar 'Green Giant'. However, observations of commercial tests indicate similar results using other cultivars. 'Domino' has been most extensively treated under commercial conditions.

Ethephon treatments applied when no more than 5% of fruit are in a red or coloured stage (50% or more of fruit surface red, through to full red colour). Optimum harvest time after ethephon application has been approximately 14 days.

Application Rates

Ethephon rates used have been in the range of 0-10,000 ppm ethephon. This has equated (approximately) to 0-10 L/ha Ethrel.

Optimum rate found so far is 5,000 ppm ethephon (approximately 5 L/ha Ethrel).

5 in 1000

1 in 200

Calcium Additive

Calcium Hydroxide (builders lime) has been added to ethephon sprays at the rates of 0.1M, 0.5M and 1.0M. The 0.1M concentration appears satisfactory and equates to about 10-12 kg/ha of $Ca(OH)_2$.

Role of Ca

Calcium has been found to reduce the abscission - inducing effects of ethylene in both leaves and fruit of several species. Part of this Ca inhibition of abscission may be related to the cementing effect the Ca may have on the cell walls through the formation of salt bridges between pectic components. There may be other effects as well, some experiments in the literature suggesting the Ca effect on abscission may be more related to deferral of senescence development than to the cementing effects of Ca on the cell walls.

This latter theory appears to have some credence, since the addition of $Ca(OH)_2$ in the capsicum experiments has led to a slowing down of fruit ripening when compared to equivalent rates without added Ca. The rates of ripening however are still considerably faster at the higher ethephon rates with added Ca than the untreated.

A number of Ca compounds have been reported on in the literature, with Ca acetate and chloride also proving successful. However some damage is reported from the chloride form and the acetate form is expensive. The hydroxide form works, and is the cheapest and most readily available. However it can be difficult to use and I intend looking at some other forms of Ca (perhaps next season).

Experimental Results

Capsicum - Field Ripening With Ethrel

- Treatments applied with 2% of fruit at forward colour stage.
- Applied late October.
- Calcium Hydroxide added to spray to reduce leaf loss.

% Red Fruit			
	After 1 week	After 2 weeks	After 3 weeks
Untreated	1	9	23
1000 ppm	1	11	34
2500 ppm	1	21	43
5000 ppm	1	37	41

% Sunburnt Fruit				
	After 2 weeks		After 3 weeks	
	No calcium	Calcium	No calcium	Calcium
Untreated	4	3	10	8
1000 ppm	3	6	9	7
2500 ppm	14	6	10	5
5000 ppm	15	7	28	7

NEWS RELEASE

CAPSICUM RESEARCH TO BE PRESENTED AT FIELD DAY

The results of a QDPI capsicum project funded by the Bundaberg Fruit and Vegetable Growers' Association will be presented at a field day on Thursday 28th November at the Bundaberg Research Station.

The two year long project looked at the effects of plant densities and fertiliser rates on the production of capsicums in the Bundaberg region.

QDPI horticulturist, Mr Jason Olsen said, "The results of this project indicate that regardless of the capsicum cultivar being grown, plant density and the nitrogen status of the plant can drastically alter marketable yield. Fruit size is especially sensitive to plant density. Growers will be able to see this first hand at the field day".

Also at the field day seed company representatives will be available for discussion about their cultivars featured in the trials.

The field day will begin at 2.00pm with an official opening by Mr Don Halpin, one of Bundaberg's leading capsicum growers. Topics to be covered at the field day include capsicum nutrition, plant density results, a demonstration of rapid sap testing, field ripening of capsicums using "Ethrel", and seed company displays of capsicum cultivars.

There will be ample time for people to view the trials and seed company displays before the field day closes at 5.00pm.

(Media Contact: Jason Olsen, Bundaberg Research Station. Phone (071) 55 6244
Fax (071) 55 6129)