Effects of Water Table Depths and Fertilizer Treatments on Yield and Quality of Tomatoes

by

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ABSTRACT

M.Sc. Agricultural Engineering

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A field lysimeter experiment was conducted during 1993 and 1994 using 4 water table depths (WTD) (0.3, 0.6, 0.8, and 1.0 m), 3 treatment levels of calcium (0, 1500, and 2500 kg/ha) and potassium (0, 160, and 400 kg/ha), to determine their effects on tomato quality and yield. Plant parameters measured included: yield (fruit/plant), fruit height, maximum and minimum equatorial width, degree of catfacing (scale of 1 to 5), and sunscald (scale of 0 to 2).

Water table treatment was usually highly significant for the parameters measured at harvest. Largest height, equatorial width and yield of tomato fruit occur with 0.6 to 0.8 m WTD. Fertilizer treatments were rarely significant by WTD, but if they were, they tended to be in the 0.3 or 1.0 m WTD. Maintaining a WTD of 0.6 to 0.8 m and fertilizing with 160 kg/ha of K can improve quality and total yield of tomatoes.

RESUME

M.Sc. Génie Rural

Leif Trenholm

Effects du Niveau de la Nappe D'eau et de la fertilisation sur le Rendement et la Qualité des Tomates.

En 1993 et 1994, à l'aide de lysimètres, l'effet de 4 niveaux de nappe phréatique (NNP)(0.3, 0.6, 0.8, et 1.0 m de la surface du sol); de 3 traitements de calcium (0, 1500, 2500 kg/ha) et de potassium (0, 160, 400 Kg/ha) sur le rendement et la qualité des tomates, a été étudié. Le rendement (nombres de fruits/plant), les dimensions des fruits, la sévérité de la face de chat (échelle de 1 à 5), ainsi que l'insolation (échelle de 0 à 2), ont été mesurés.

Pour tous les paramètres mesurés lors de la récolte, le NNP a été significatif. C'est à un NNP de 0.6 à 0.8 m qu'ont été récolté les plus gros fruits et que le rendement a été le meilleur. Les traitements avec fertilisants ont rarement été significatifs, mais lorsqu'il l'ont été, ce fut au NNP de 0.3 ou 1.0 m. Des nappes phréatiques entre 0.6 et 0.8 m de la surface, et la fertilisation avec 160 kg/ha de potassium peuvent augmenter le rendement et la qualité des tomates de champs.

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Nomenclature

Ca	:calcium
CD-SI	:controlled drainage - subsurface irrigation
cm	:centimetre
Et_c	:crop evapotranspiration
ft	:feet
g	:gram
ha	:hectare
K	:potassium
kg	:kilogram
m	:metre
mm	:millimetre
NO_3^--N	:Nitrate nitrogen
t	:tonne
WTM	:water table management
WTD	:water table depth
°C	:degree celsius
$	:dollars
%	:percent

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1.0 INTRODUCTION

The tomato (*Lycopersicon esculentum* Mill.) is the world's most valued vegetable after white potatoes (*Solanum tuberosum* L.)(McCollum, 1980). World tomato production has increased 55 % from 1971 to 1986 at an average annual increase of about 1.3 million tonnes (MT) (Stevens, 1986). Tomatoes represent 31 % of Canada's total vegetable production (FAO, 1991). Thus, the tomato is an important crop on the world stage and within Canada. Tomato production in Canada occurs for the most part in British Columbia, Ontario and Québec. From 1980 to 1990, Québec production area varied between 1300 to 1600 ha (Bureau de la Statistique du Québec, 1981, 1991; Statistics Canada, 1991). Yields during the 1980s in Québec ranged from about 7 to 14 t/ha (Bureau de la Statistique du Québec, 1988). A good commercial yield for tomatoes under irrigation is 45 to 65 t/ha (Doorenbos and Kassam, 1979). This shows that Québec is far from producing optimum yields. A better understanding of the field conditions, and how they affect post harvest parameters can greatly improve quality of the fruit. Factors, such as mineral nutrition and soil moisture, can be manipulated in an effort to find the optimal conditions for plant growth.

Historically speaking, there is an average annual moisture surplus in Québec. However this water is not distributed evenly throughout the year. Spring snowmelt and autumn rainfall exceed evapotranspiration. There is often a deficit of soil moisture in the middle of the growing season, which may lead to water stress in the plant (Memon *et al.*, 1987).

Periods of high soil moisture could cause anaerobic soil conditions in the root zone, erosion, and reduction of field trafficability during crucial planting and harvesting periods. In an effort to eliminate these problems, subsurface drainage systems were installed to remove excess water from the soil (Schwab *et al.*, 1981). However, excessive drainage may remove water needed by the crop later in the growing season and may increase leaching of plant nutrients from the soil (Council for Agricultural Science and Technology, 1988). With a relatively inexpensive modification to an existing drainage system, the water table can be controlled (Madramootoo *et al.*, 1993). Controlled drainage permits storage of rainfall or irrigation water in the soil profile by means of a control chamber. In addition to storing soil moisture, water can be added to the drains to raise the water table to supply water to the root zone through capillary rise. This system using controlled drainage-subsurface irrigation (CD-SI) is referred to as water table management (WTM).

Greater storage of soil moisture by controlled drainage and subirrigation results in less runoff and more denitrification, and therefore decreases the amount of agro-chemicals released into the local watercourses (Madramootoo *et al.*, 1993; Evans, 1993). Water table management is energy efficient because the water does not have to be lifted above the ground or operate under high pressure like conventional sprinkler systems (Benz *et al.*, 1981).

This system is beneficial to tomatoes in drought conditions since irrigation gives a distinct advantage in maintaining growth and obtaining good yields (Gould, 1992; Rudich and Luchinsky, 1986). Flooded crops, such as tomatoes which lack oxygen in the soil profile leads to physiological responses which result in decreased crop yields across a wide range of plant species (Hoffman, 1990; Kozlowski, 1984). WTM is capable of removing excess water after periods of heavy rain, thus reducing the occurrence of waterlogging (Memon *et al.*, 1987).

Balanced mineral availability ensures normal crop development, maximizes growth, combats disease and physiological disorders, and improves quality and shelf-life (Hobson, 1990). Manipulation of the nutrient supply is essential in achieving good quality, high yielding tomato plants, necessary for profitable production (Adams, 1986).

Water table management has the capability of delivering the optimal water table depth to tomatoes with low operating costs and a reduction in non point source pollution. Implementation of an appropriate WTM and a balanced nutrition for tomato could produce higher and better quality yields, possibly prolonging fruit marketability after harvest.

1.1 Objectives

The objectives of this research project were to:

1. Determine the effect of four water table depths, and three treatment levels of calcium and potassium on tomato plants grown in field lysimeters.
2. Ascertain the optimum water table level and fertilizer treatment for maximum crop yield.
3. Establish the best water table depth and fertilizer regime for improved fruit quality.

1.2 Scope

This experiment attempted to simulate field conditions of tomatoes grown on a sandy loam soil. Only one cultivar of tomato, the 'New Yorker' was used. This variety was chosen because it produces its entire crop over a period of a few days, and matures within 64 days after transplanting (Dubose, 1985).

2.0 LITERATURE REVIEW

2.1 Soil, Water, Plant and Air Continuum:

All plant growth and reproduction is in response to dynamic interactions with elements in their environment. These elements consist of soil and air temperatures, available soil water and air, sufficient light and carbon dioxide for photosynthesis, balanced mineral nutrition, and appropriate rooting medium which supplies adequate support (Rendig and Taylor, 1989). Water is the medium in which all chemical reactions in plants take place, and without water the whole building process would cease to function. Part of the water taken up through the roots is retained within the cells and tissues, but a majority of the moisture flows up through the plant where it is evaporated through the leaves. This flow of water going from the roots to the leaves is referred to as transpiration, and is used to translocate inorganic salts in solution and cool the plant by transpiration (Dorey, 1980). Another possible avenue for moisture to enter aerial plants is the ability of the plant's surface to absorb water, provided that a humid atmosphere or liquid film is in contact with an above ground part of the plant. Fully hydrated, water makes up 80 to 90 % of the fresh weight in plants (Walton, 1988). Wherever plants grow, their development is limited to some degree by either too little or too much water (Kozlowski, 1968). Although an excess of water (flooding condition) can be devastating to crop production, water deficit stress (drought condition) reduces plant growth and crop yield more than all other environmental stresses combined, and this is attributed to the dwindling water supplies in many regions of the world (Kramer, 1983). However, suitable amounts of water alone will not produce high yields and quality tomatoes. Liebig's Law of Minimum states, "if any growth factors are in short supply, plant growth often will be reduced in proportion to the reduced supply rate" (Marschner, 1986). Supplementing these limiting factors will increase growth, up until a maximum, where adding more will have no effect. However, if two or more of these factors limit growth, then supplementing one will have little effect, but increasing the amount of all of them will result in a dramatic response (Rendig and Taylor, 1989; Brady, 1984).

2.2 Tomato Plant Physiology

2.2.1 Planting and length of growing season

The growing season for tomatoes in Québec is short because this crop cannot tolerate temperatures below 10°C (Environment Canada, 1982), and definite chilling injury occurs around 4°C (Gould, 1992). To shorten the growing season, one must choose a variety which requires the fewest days after transplanting to reach maturity, or what are called early type tomato plants (Dubose, 1985). Secondly, the seed must be germinated and grown in greenhouse conditions, and only transplanted to the field when there is no threat of adverse temperatures (Geisenberg and Stewart, 1986; Picken *et al.*, 1986). Spacing during planting ranges from 0.3-0.6 x 0.6-1.0 m resulting in a population of 40 000 plants/ha. Rooting depth of mature irrigated tomato crop grown in deep permeable, well drained soil is 0.7 to 1.5 m. Maximum rooting depth can be reached in about 60 days after transplanting. Throughout the entire growing season, over 80 % of total water uptake occurs in the first 0.5 to 0.7 m. Under maximum evapotranspiration (ET_m) of 5 to 6 mm/day, water uptake to meet full crop water requirements is affected when more than 40 % of total available water has been depleted (Doorenbos and Kassam, 1979).

2.2.2 Soil moisture and growth stages

For high yield and good quality, the tomato plant needs a controlled supply of water throughout the growing period. Under water limiting conditions, some water savings may be made during the vegetative and ripening periods. Tomatoes are most sensitive to water deficit during and immediately after transplanting, at flowering, and fruit development (Doorenbos and Kassam, 1979). Water consumption of tomatoes starts from low values at the beginning of growth, and then increases gradually until flowering, after which it climbs to a maximum during the peak of fruit ripening. At this time the leaf area is at maximum. Water consumption remains constant until the onset of ripening after which, in determinate varieties, it decreases (Rudich and Luchinsky, 1986). The approximate range of seasonal evapotranspiration (ET_c) for tomatoes is 300 to 600 mm. This seasonal value takes into account the crop characteristics, time of planting, and stages of crop development and general climatic conditions (Doorenbos and

Pruitt, 1977). This section would like to investigate the role of soil moisture with respect to crop development to better understand the tomatoes water needs. According to Rudich *et al.* (1977), the growing season is divided into five stages:

1- Germination, emergence and establishment of plants.

2- Vegetative growth (end of stage 1 to start of flowering)

3- Reproductive growth (until first full size mature fruit)

4- Fruit development (until 20 % of fruit changes colour)

5- Ripening stage.

2.2.2.1 Germination stage

Depending on the stage of development, the needs of the plant change. Throughout the germination process, the nutrients which provide the energy come from within the seed, but once new cells become specialized, the seedling will search for nourishment from its surroundings (McCollum, 1980). Various seeds have the ability to withstand dehydration and can be stored in dry conditions for several years. Once the seeds have germinated and the root cells have become vacuolated, the newly formed tissue is usually more susceptible to dehydration. Once germination has begun, the tomato seed requires a suitable amount of moisture and an adequate supply of oxygen (Dorey, 1976).

2.2.2.2 Vegetative stage

A seed is considered fully germinated once it produces a functioning plant which under proper environmental conditions has the capability to grow continuously. At this point, the tomato plant enters the vegetative stage (Janick, 1986). This stage is distinguished by the most rapid rate in growth in the plant's life cycle (Walton, 1988). To support this growth, various inputs are extracted from the environment surrounding the plant (McCollum, 1980). Not only should there be a balanced nutrient supply in the soil, but factors such as, soil pH, moisture, bulk density, and temperature, along with light intensity should be at appropriate levels to allow for optimum vegetative growth (Adams, 1986).

The influence of irrigation during the vegetative stage did not enhance growth, and had no effect on the flowering dates, nor on the number of inflorescences and their rate of appearance, although combined irrigations in reproductive and fruit development stages or vegetative and reproductive stages produced the most vigorous vegetative growth (Rudich et al., 1977). Stegman *et al.* (1981) found little yield reduction for sunflowers (*Helianthus annus* L.) as long as soil water depletions are less than 50 to 60 % in early vegetative stage. According to Doorenbos and Kassam (1979), the crop factor (K_c) which reflects the consumptive use of water for specific growth stages, was not the overall highest stage for the growing season at 0.7 to 0.8, demonstrating that the vegetative stage is not the most water sensitive stage.

However, with an increase in soil water tension, there is a decline of potential gradient between soil, plant and atmosphere. This slows down the transpiration rate, which becomes the limiting factor in the plant development (Rudich and Luchinsky, 1986).

Root growth is important in this stage, because as environmental conditions favour root growth, the larger the root system, the greater the area for absorption of nutrients. The effect of fluctuating water tables and intermittent flooding on crop yield depends on the frequency and duration of high water tables. A high water table early in the growing season will limit root penetration, and later in the growing season the shallow root system will not be able to provide the plant's moisture needs (Hoffman, 1990).

High soil bulk density restricts root extension and creates relatively low hydraulic conductivity resulting in anaerobic soil conditions (Voorhees *et al.*, 1986). Tomato plants tend to grow a denser root system at soil water potentials which are slightly less than field capacity (Michelakis and Chartzoulakis, 1988). Excessive water adversely affects shoot growth by restricting internode elongation, leaf initiation and expansion, by inducing epinasty of leaf and petiole, leaf senescence, leaf chlorosis, and leaf abscission. Swelling of the stem base is a common occurrence in flooded tomato plants. The most common type of root regeneration in flood conditions is the development of adventitious roots on the stem above the soil and usually in the flood zone. Plants equipped with these roots can tolerate flooding or recover more quickly and completely than if the roots were removed (Kozlowski, 1984).

2.2.2.3 Reproductive stage

This is the final stage of growth, and it begins with the first floral primordia being formed (Janick, 1986). As the tomato plant gets older, the genetic control in charge of the flowering process will make the plant more likely to flower. At this stage of development and given the right environmental conditions such as water, light, and temperature are important in promoting floral initiation (Walton, 1988).

The reproductive stage is particularly susceptible to water deficit stress. Yield reduction is minimal in the period from budding to last anther for sunflowers if the soil available water is decreased by less than 30-40 % (Stegman and Lemert, 1981). According to Doorenbos and Kassam (1979), the tomato plant's reproductive stage has the highest crop factor (K_c) than any other growth stage. Little is known about the effects of water stress on floral initiation, but evidence suggests that drought conditions reduce the number of flowers produced. For example, when compared to drought conditions, irrigated tomatoes increased the percentage of flowers that set fruit, decreased blossom-end-rot and reduced cracking in tomatoes (Kozlowski, 1972). Irrigation in the reproductive and fruit development stages resulted in increased yields by 120 %. Irrigation only in the reproductive phase produced a vigorous growth, but there was no influence on the number of inflorescences, nor rate of flowering during the first 24 days of flowering. (Rudich *et al.*, 1977).

When tomato plants are excessively watered, the leaves will curl and the fruit will usually develop blossom-end rot, whereas reducing the amount of water will allow the leaves and fruit to develop normally (Meudt, 1983).

2.2.2.4 Fruit development and ripening

Irrigation during fruit development greatly increased the percentage of rotten fruit, doubling the amount of rotten fruit and culls (Rudich *et al.*, 1977). However there was fewer rotten fruit found in drip irrigation than in sprinkler irrigation. After the reproductive stage, the water requirements decrease to below that of the vegetative stage (Doorenbos and Kassam, 1979). Over irrigation was shown to be detrimental to the processing suitability and increased the harvesting period (Alvino *et al.*, 1988). Irrigation during the fruit development resulted in a reduction in fruit quality in terms of percentage of total soluble solids, expressed in °brix values, lower viscosity, lower acidity, a reduction in colour intensity and a drop in vitamin C content. Irrigation affected the taste of fruit expressed by °brix\acid ratio. Irrigation in the vegetative stage increased this ratio, while during the reproductive and fruit development stages the ratio was decreased (Rudich *et al.*, 1977). Frequent light irrigations improve size, shape, juiciness and colour, but total dry matter and acid content are reduced, lowering the fruit processing quality. This suggests that the choice of irrigation practice depends on the type of end product desired (Doorenbos and Kassam, 1979).

During fruit development, tomatoes subjected to large amounts of direct solar radiation are prone to sunscald. Green fruits are more sensitive to this physiological disorder than ripe fruits (Grierson and Kader, 1986). Sunscald occurs when plants expose their fruits to intense sunshine for several days causing a yellow patch on the side of the tomato. Maintaining a full plant canopy will protect the crop from the suns harmful rays (Dubose, 1985). Cracking fruit is another physiological disorder which usually occurs in areas of high rainfall during ripening (Stevens and Rick, 1986). Prolonged water deficits during fruit development interrupted by heavy rainfall or irrigation leads to cracking (Doorenbos and Kassam, 1979). Cracking and splitting tendency is genetically controlled and appears to be related to skin strength and stretching ability. Cracks can occur to form small rings encircling the stem end (concentric cracking) or radiate from the stem scar end (radial cracking). Cracking incidence is affected by soil moisture, rainfall, dew, and high temperature. For instance, droplets of water that remain on the fruit for six hours or more can cause the skin of the fruit to split. This disorder not only affects the appearance, but also increases the susceptibility of fruits to pathogens and water loss (Dubose, 1985; Grierson and Kader, 1986). Another disorder known as catfacing, sometimes deforms tomatoes, and appears as enlarged scars and holes in the blossom end of the fruit. Cold weather, and high nitrogen can aggravate this problem (Scott, 1991). Dubose (1985) describes catfacing as puckers, scar tissue and deep crevices at the blossom end and suggests that cloudy, cool conditions contribute to this problem.

2.3 Effect of Drought Stress on Growth

Drought is a meteorological term, and is defined as the absence of rainfall for a long enough period of time resulting in the depletion of soil moisture and leading to plant injury (Kramer, 1983). A water deficit causes the plant to respond in two basic ways to improve its water status: (i) decrease the opening of the stomata reducing the water lost to transpiration, and (ii) a shift of photosynthates towards the support of growing a more developed root system. During drought conditions, the expansion of the roots system is beneficial in two ways: (i) it restricts the above ground growth of the plant (thus reducing further transpiration), and (ii) increasing the capacity of the roots to search for new sources of ground water (Alscher and Cumming, 1990). Under drought conditions, the first and most sensitive response of plants is the decrease in cell enlargement. This is because growth is directly associated with the cell turgor which is the amount of liquid protoplasm contained in a cell. Dehydration makes water potiential more negative resulting in a decrease in turgor pressure, reducing leaf growth more rapidly than photosynthesis and respiration. Turgor pressure is the "physical driving force" which causes an irreversible growth of the cell by applying a hydrostatic pressure on the primary cell wall (Rudich and Luchinsky, 1986). Even with soil well supplied with moisture, a plant may become deficient during the middle of a bright, warm day. As a result, guard cells of the leaves become flaccid and the stomates close, restricting water transpiration, but also restricting CO_2 uptake, thus decreasing the photosynthetic process (McCollum, 1980; Loomis and Connor, 1992; Wong *et al.*, 1979). In the extreme case, where the stomata are fully closed, photosynthesis is halted and no sugar is produced to drive the active transport in the roots. This means the roots cannot efficiently absorb nutrients for plant development (Hartmann *et al.*, 1988). This process appears to be less sensitive to water stress than either translocation or growth (Boyer, 1970). Rudich and Luchinsky (1986) suggest that water stress impairs the translocation of assimilates, which results in the accumulation of these substances in the leaf possibly suppressing photosynthesis.

2.4 Effects of Flood Stress on Growth

Flooding refers to the presence of water in soil in excess of field capacity. Flooding is the replacement of the gas (air) phase of the soil by the liquid (water) phase (Levitt, 1972). Almost all plant responses to flooding are linked to the limitation of oxygen diffusion to the root (Bradford and Yang, 1981; Kozlowski, 1984). Injury from waterlogging develops over a period of several days and progressively gets worse as the duration of the flooding continues. Wilting is usually the first visible symptom if atmospheric conditions favour transpiration. The wilting is generally assumed to result from decreased water absorption because of a sudden increase in the roots impermeability in the saturated soil. The roots resistance has been said to be attributable to the toxic effect of high levels of trapped carbon dioxide and/or the immobile ethylene produced in the soil and by the plant (Kramer, 1983; Bradford and Yang, 1981).

2.5 Balanced Mineral Nutrition

An increase in nitrogen, potassium, magnesium and lime resulted with an increase in tomato quality (Winsor *et al.*, 1967). Research has shown that certain elements are essential for plant growth and each element must be in the middle range of a specific concentration range, with elements supplied in the right combination and adequate soil moisture for optimum plant growth (Brady, 1984). Effects of calcium and potassium will be discussed in this section.

2.5.1 Calcium (Ca)

Calcium plays a vital role in maintaining the integrity of the cell walls, and is found in the form of calcium pectate in the middle lamella, which acts as the cementing layer between the cells (Janick, 1986), and regulate several intracellular functions (Glenn *et al.*, 1988). Calcium is not easily translocated out of the leaves once it is assimilated, making it a limiting nutrient for rapidly growing tissues. Therefore growing tomato fruit are dependent on the calcium being transported with the water in the xylem. In times of water stress, rapidly expanding tomatoes will receive limiting amounts of Ca. Calcium is affected by extremes in relative humidity because these conditions restrict soluble calcium in water for transpiration to reach actively growing cells (Adams, 1986). Lack of calcium in the vegetative stage of tomato plants affects the colour of young leaves (Blanchard, 1992). A deficiency in calcium has been closely linked to weakening of the middle lamella promoting physiological disorders like blossom-end rot (BER), which allows easier entry for opportunistic diseases. The incidence of BER is dramatically increased when the calcium concentration in the fruit is less than 0.08 %(on a dry weight basis), while when it is greater than 0.12 %, the disorder rarely appears (Grierson and Kader, 1986; El-Gizany *et al.*, 1986). Calcium availability can have a marked effect in minimizing losses due to cracking (Stevens and Rick, 1986). Accumulation of calcium, particularily in the blossom scar half of the fruit, was progressively reduced by increasing salinity. The occurrence of BER also increased with salinity (Geraldson, 1957; Ehret and Ho, 1986; Scott, 1991). Calcium uptake by young plants was decreased by 85-88 % at a very salinity (17 mS/cm), even though this level was achieved by adding Ca and K to the nutrient solution (Adams, 1986). Conditions favouring calcium deficiencies in tomato are acidic soils, high soil concentration of K^+, NH_4^+, and Mg^{2+}, low or fluctuating soil moisture, and high atmospheric humidity (Compendium of Tomato Diseases, 1991). Spraying fields deficient in calcium with a solution containing 5.6 kilograms of calcium chloride and 1122.9 litres of water per hectare on golf ball size tomatoes may control the problem of BER (McKeen, 1972).

2.5.2 Potassium (K)

Potassium is unusual because it makes no direct contribution to the cellular structure of the plant. Its main function seems to be a regulator for many metabolic processes in the cells (Adams, 1986). It is highly mobile within individual cells and tissues, as well as by long distance transport via the xylem and phloem. The K requirement for optimal growth is approximately 2-5 % of the dry weight of fruits. When soil moisture is limited, loss of turgor and wilting are typical of potassium deficiency. The lower tolerance of plants lacking K is mainly because of the potassium's role in stomatal regulation and because K is a principal osmotic solute which maintains a high tissue water level even in times of drought. Plants receiving not enough K are often more susceptible to damage, which at a cellular level, is related to lack of water (Marschner, 1986). High potassium improved all aspects of fruit quality (Adams, 1986). Low K resulted in shortening of growth period, increased climacteric respiration (Ho and Hewitt, 1986), and uneven ripening (Stevens and Rick, 1986). Environmental conditions promoting potassium deficiencies in tomatoes are light sandy soils, leaching rains, acidic and organic soils, and inadequate fertilization. Fruit defects associated with potassium shortage include puffiness, ripening diseases, softeness, irregular shape, and low acidity. These physiological disorders will occur without foliar symptoms or reduced yield, suggesting that in some situations potassium requirements for fruit quality are greater than for vegetative growth or maximum yield (Compendium of Tomato Diseases, 1991).

2.6 Effects of Irrigation

In many crops extractable soil water content can be reduced by 50 % before there is any influence on physiological activity leading to loss of crop productivity. In fact mild water deficits do not necessarily reduce yields, and in some cases can actually enhance yields (Turner, 1990). Sprinkler irrigation promotes free moisture conditions which provide good environments for humid-associated diseases, and the wet ground furthers the development of rot. Comparatively, furrow and drip irrigation diminish the occurrence of humid diseases, but might favour the development of pests and diseases which prefer dry conditions (Geisenberg and Stewart, 1986).

Bui and Osgood (1990) found that sprinkler systems were costly to operate, wasted water, and could not adequately irrigate on a timely basis following a harvest. They also found that surface drip irrigation distributed water more uniformly, and with higher efficiency, but was often damaged during harvesting operations. Therefore, they decided to install subsurface drip irrigation to maximize the benefits inherent in that system. Phene *et al.* (1983) permanently installed a similar irrigation system deep enough so that it would not interfere with cultivation practices, effectively eliminating the annual handling and installation of laterals in row crop fields. Results after three years show this system can be a feasible, valuable, and efficient method of irrigating row crops.

2.7 Effects of Subsurface Drainage

Subsurface drainage systems have been installed in the St. Lawrence lowlands of Québec and Ontario, and other humid regions where annual precipitation exceeds evapotranspiration. These regions are characterized by low soil permeability and flat topography (Broughton, 1972). Good soil drainage is essential to the proper management and conservation of wet, fertile soil being used in agricultural production. Subsurface drainage is a technique for controlling the water table using a drainage pipe which has been installed at a specific depth underground (Irwin, 1991). Subsurface drainage increases yield as it allows earlier planting, thus potentially offsetting the cost of the drainage system by giving a potential dollar return. The average benefit for Illinois soils range from $ 37 to $ 156 per hectare (Wendte and Lembke, 1977). Subsurface drainage reduced the number of high flow rates by 50 % and decreased slightly the average peak flow rate as compared to surface runoff during rainstorms. By altering the runoff/infiltration balance it contributes to an improvement in soil structure, lowers surface runoff velocities, and reduces the rate of erosion (McLean and Schwab, 1982). Peters *et al.* (1982) stated the potential for compaction can be reduced by using deep drainage depths. This may compound the lack of infiltration into the soil, possibly increasing the amount of surface runoff and erosion.

Drainage systems which do not control their outflow may not allow for optimum conditions, such as, excessive drainage and leaching of nitrates. Results of several North Carolina studies suggest that subsurface drainage increases outflow by 20 % compared to natural conditions (Evans, 1993). Therefore subsurface drainage allows a smaller amount of soil moisture to remain stored beneath the soil surface. Once the water table reaches 1.5 m below the surface of sandy soils, the maximum corn (*Zea mays* L.) yield was not attained. However, yields were improved by raising the level of a nearby stream which produced a higher water table (Doty *et al.*, 1984). Water retention characteristics of some sandy soils are such that 15 % of the soil volume will be drained. This amount of soil moisture loss results in excessive drainage and therefore reduces the quantity of water available for crop evapotranspiration (Rashid-Noah, 1981).

The main factors affecting nitrogen loss from agricultural fields by leaching are the flow of water through the soil profile, and the amount of NO_3^- available for leaching at the time of water movement (Blackmer , 1987). Nitrate-nitrogen (NO_3^--N) is a common pollutant of water (Schwab *et al.*, 1993). It is the form of nitrogen most susceptible to leaching because it is an anion, and therefore, not attracted to soil particles. Unless NO_3^--N is removed from the soil solution by some process such as immobilization, plant uptake, or denitrification, it is free to percolate below the crop root zone (Blackmer, 1987). Nitrate ions in deeper layers are leached into the groundwater. They could also enter streams, lakes and rivers via subsurface drain outlets (Füleky, 1991).

2.8 Water Table Management (WTM)

Water table management is a dual purpose system which uses a subsurface drain pipe system for both controlled drainage (CD) and subsurface irrigation (SI) (Madramootoo *et al.*, 1993). Site conditions for effective CD-SI are a flat topography (slope < 2 %), and a natural impermeable layer must exist within a 10 ft (≈ 3 m) of the soil surface (Council for Agricultural Science and Technology, 1988). With these conditions met, a control chamber is placed at the drainage system outlet, allowing water to flow only when it reaches a predetermined height, usually set by an adjustable overflow pipe or weir (Hoffman, 1990). Papineau (1988) concluded that 15 000 ha of land in Richelieu and St. Hyacinthe counties of Québec were suitable for subirrigation. Crucial to the peak performance of a WTM system is proper design, and appropriate management (Shirmohammadi *et al.*, 1991). According to Hoffman, (1990), the primary design and operational objectives of a WTM system are to:

- Allow timely farming operations to be done as soon as possible;
- Reduce crop stresses caused by excessive soil water conditions;
- Reduce or eliminate stresses caused by deficit soil water;
- Control salinity and alkalinity;

◂ Minimize harmful off-site environmental impacts; and

◂ Conserve water supplied by precipitation; minimizing irrigation water requirements.

When designing and operating a CD-SI system, there are at least three modes to consider. First, the steady state mode requires that the drains be spaced to achieve and maintain the desired water table depth, even during high evapotranspiration. Secondly, the transient state requires that the water table depth be raised to a desired level within an acceptable period of time. The third mode requires that the system must satisfy both the irrigation and drainage requirements (Skaggs, 1979; Doty *et al.*, 1983). Farmer-managed systems have been operated by controlling the water level in accordance with the crop needs and growth requirements. This is accomplished by raising the water level close to the surface after planting and progressively lowering the water table in an effort to keep the roots in the capillary fringe as the root develops (Doty *et al.*, 1983; Wenberg, 1976).

2.8.1 Effects of WTM on crop yields

Controlling the water table depth conserves drainage water, reduces drought stress and irrigation requirements (Doty *et al.*, 1987). A total water management system which controls the water table increases the yield response for a variety of crops (Cooper *et al.*, 1992; Doty *et al.*, 1975; Doty *et al.*, 1985; Kandil and Willardson, 1992; Madramootoo *et al.*, 1993). Obtaining maximum yields for tomatoes can be accomplished by maintaining the soil moisture level close to field capacity from the soil surface to a depth of 0.9 m

(Giardini *et al.*, 1988). Soliman *et al.* (1978) determined that a water table depth of 0.7 to 1.0 m is needed for high tomato yields.

2.8.2 Environmental impacts of WTM

Improved drainage in humid regions may increase the amount of pollutants lost to surface waters, while reducing the losses of others (Gilliam and Skaggs, 1986). Water table management controls the water table depth by restricting the amount of subsurface flow (Hoffman, 1990). By raising the water table, more soil is kept in a saturated state, producing anaerobic conditions which promote denitrification (Gilliam and Skaggs, 1986; Gilliam *et al.*, 1979; Gambrell *et al.*, 1975a, b). Lalonde (1993) suggests that the net environmental benefit of controlled drainage pertaining to nitrate leaching is due to decreased drain flow.

Using shallow WTD, Kalita and Kanwar (1993), observed over three years, a consistent decrease in the nitrate concentration of groundwater. Comparing WTDs of 0.3, 0.6 and 0.9 m, a WTD of 0.3 m was deemed most suitable for improving water quality, whereas a WTD of 0.9 m delivered the maximum yield for corn. They recommended a WTD of 0.6 m, to optimize crop and water quality objectives. Controlled drainage may have little effect on total nitrogen concentrations compared to no control, since Total Kjeldahl Nitrogen concentration is somewhat increased, while concentration of NO_3^--N is decreased through denitrification (Evans *et al.*, 1989). Controlled drainage significantly reduces nitrogen transport at the edge of the field because of a decrease in outflow volume compared to no control, and to a lesser degree by denitrification (Evans, 1993).

Restricted drainage, resulting in a shallow water table, allows water to move through the soil profile by capillary movement. This situation results in soluble salts accumulating in the capillary fringes due to evaporation (Grimes and Henderson, 1986). This process effectively "locks" soluble minerals into the soil profile so they can be reused, and reduces the amount of leached salts which could eventually cause pollution.

2.9 Summary

Throughout the life of a tomato plant, certain conditions must be fulfilled in order to achieve maximum yields. Furthermore, these conditions do not necessarily have to remain constant, and will usually vary from one growth stage to another. In order to eliminate an limiting factors which could reduce the plants productivity, an integrated approach of all inputs is required. All environmental stresses and timely application of inputs must be considered, not only for high yields, but for increased fruit quality as well.

Water table management gives farmers more control over field conditions, permitting them to cater to the specific needs of the crop. It allows for increased soil moisture storage reducing the risk of drought stress, while inhibiting the chance of flood stress. Another important benefit of CD-SI systems is the ability to reduce the leaching of soluble agro-chemicals, preventing pollution, and allowing for reuse of drainage water.

3.0 MATERIALS AND METHODS

3.1 Experimental Setup

During 1993 and 1994, an experiment was carried out at the Horticultural Research Centre, Macdonald Campus of McGill University, located in Ste. Anne de Bellevue, Qc.

Three fertilizer treatments of potassium and calcium were applied in a central composite design, and were factorially combined with the four water table treatments. Potassium (0-0-20, K_2O) was applied in three levels : 0 (low),

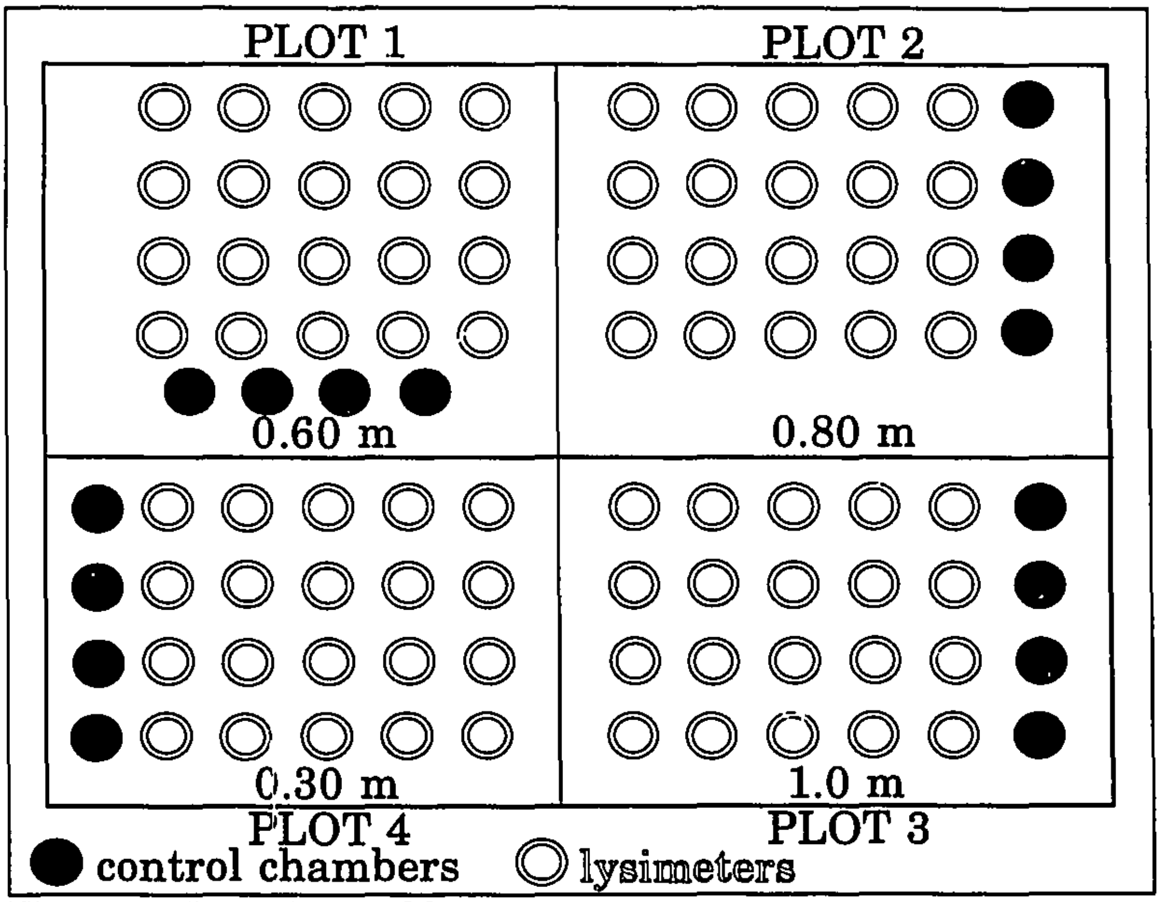


Figure 3.1 Experimental layout

160 (medium) and 400 kg/ha (high) at harvest. Calcium foliar spray (1.0 % (w/v) $CaCl_2$) began July 6, 1994 and ended on August 3, 1994. Each application required approximately 2.5 l of solution, resulting in the equivalent of 500 kg/ha. It was applied as follows: low level plants never received treatment, medium level plants received one treatment every two weeks, and high treatment plants received one application per week. This resulted in the medium treatment receiving 3 applications (1500kg/ha), and the high receiving 5 applications (2500 kg/ha). Only 5 combinations of fertilizers were used namely all permutations of high and low level treatments, and only the medium Ca- medium K combination. Five permutations were used because it is a multiple of the total number of lysimeters, and it also allows the experiment to focus on the extreme fertilizer regimes. A central composite design was used since not all of the fertilizer interactions were investigated.

The physical setup consisted of 80 lysimeters divided evenly into four water table groups (Fig. 3.1). Each group of lysimeters was placed in a 1.0 m x 1.0 m grid pattern, and groups were placed 2.0 m apart. To maintain the water table depths, four water table control chambers were connected randomly to five lysimeters, via a 40 mm polyethylene pipe to maintain the water table depths. Border rows plants of the same cultivar were placed around and between the four groups at a spacing of 1.0 m to negate edge effects.

3.2 Lysimeters and Control Chamber Construction

Both the lysimeter and control chamber were constructed from a double wall polyethylene pipe, (400 mm inner diameter and 1.2 m deep) sealed at the bottom with concrete, and were buried with 0.1 m protruding above the soil to prevent surface water from entering the lysimeter. In an effort to simulate a subsurface drain lateral, each lysimeter (Fig. 3.2) contains a 40 mm perforated pipe covered with a filter sock, which was connected to the 40 mm non-perforated pipe which joins and seals the lysimeter and control chamber.

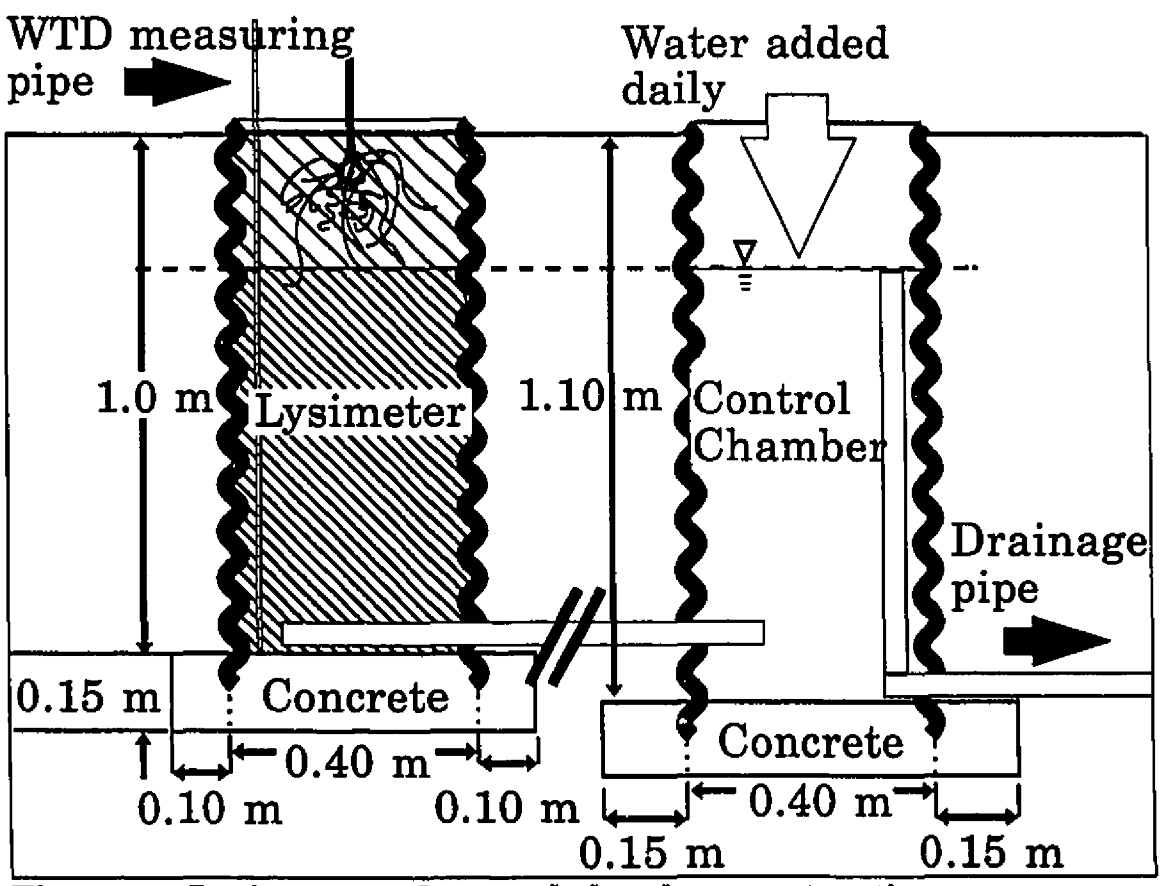


Figure 3.2 Lysimeter and control chamber construction

Each lysimeter is equipped with a piezometer to observe the actual depth of the water table. The actual water table depth settings were 0.25, 0.50, 0.75, and 1.0 m for both growing seasons. The soil was a Courval sandy loam and was packed to a bulk density of approximately 1.1 g/cm^3. Analysis of the soil particle size showed a composition of 85 % sand and 15 % clay.

The control chamber (Fig. 3.2) supplied water by gravity to the lysimeter via the 40 mm polyethylene pipe. The water table levels were fixed using different lengths of overflow pipes which were connected to buried tile drains.

3.3 Agronomic Practices

Tomatoes (cv. New Yorker) were seeded in Promix (April 14, 1993 and April 15, 1994) in the greenhouse. One week later they were transplanted to cell packs, using Promix and watered with a transplant solution of 10 g/l of 10-52-10 with micronutrients. Every two weeks, the cell packs were fertilized with 20-20-20 (@ 2.5 g/l). A week prior to planting, the seedlings were hardened outdoors. One seedling was transplanted per lysimeter on June 5, 1993 and May 30, 1994. Any damaged or dead plants within the first three or four days were replaced.

Before transplanting, each lysimeter and surroundings were hand tilled. In 1994, Glyphosate-isopropylammonium (Roundup) (Worthing and Hance, 1991), was applied a week before transplanting to remove weeds at a rate of 600 l/ha (1 % v/v) resulting in 2.88 kg active ingredient per hectare. Lysimeters were fertilized at transplanting with equal amounts of nitrogen (34-0-0, as ammonium nitrate) and rock phosphate (0-27-0, P_2O_5) which were equivalent to 90 kg/ha and 145 kg/ha, respectively.

Daily visits to the lysimeters included topping up of control chambers and hand weeding. All flower and buds were removed daily for four weeks after transplanting, in order to encourage vegetative development. Three weeks after transplanting, a side dressing of nitrogen was applied as ammonium nitrate at a rate of 45 kg/ha. Once the fruit grew to 10 mm in diameter, a foliar spray of calcium was applied weekly to specific plants, only on sunny days, until harvest. Weeding was done on a need basis, but usually it was thoroughly done by hand and with a mechanical trimmer every two to three weeks.

The tomato crop was harvested on August 11h and 23rd, 1993. All fruit which were mature green or riper on August 11th were harvested, and the rest were harvested on August 23rd. The second years' crop was completely harvested August 9th, 1994.

3.4 Plant Parameters

Soil fertility measurements were taken in the spring and fall 1993, and in the fall of 1994 at 0 to 0.15 and 0.45 to 0.60 m depths using an auger. Available K was determined using the Mehlich III Procedure (North Carolina, 1984), and available NO_3^- and NH_4^+ were analyzed as described by Keeney and Nelson, 1982. Water table depths were measured weekly using an electronic beeper in the WTD measuring pipe. Soil moisture measurements were accomplished using Time-Domain Reflectometry (TDR) at two depths of 0 to 0.15 m and 0 to 0.60 m (Topp and Davis, 1985). TDR measurements were performed approximately every two weeks using three aluminum probes which were placed in each lysimeter prior to transplanting tomatoes. The height of the plant total length of main and adventitious shoots were measured during different stages of growth in 1993. The weight of the tomato plants were measured after the final harvest in 1993 and 1994. This weight excludes the roots and fruit.

During harvest, fruit height (stem scar to blossom scar), and maximum and minimum equatorial diameter were measured for each tomato, using calipers. Table 3.1 shows the size categories for different ranges of maximum and minimum equatorial diameters.

Table 3.1 USDA (1973) Size standards for Tomatoes

Size Categories	Minimum Diameter (mm)	Maximum Diameter (mm)
Cull	----	47.6
Extra Small	47.6	54.0
Small	54.0	57.9
Medium	57.9	64.2
Large	64.2	73.0
Extra Large	73.0	88.1
Maximum Large	88.1	----

United States Department of Agriculture (USDA, 1973) colour classification is used to indicate the stage of ripeness for mature tomatoes of a red flesh variety. There are six categories describing tomato ripeness; mature green, breakers, turning, pink, light red and red. Tomatoes which are full size and completely green in colour (vary from light to dark green) is classified as "mature green". The next stage is called "breaker", and signifies that there is a definite break in the colour from green to tannish-yellow, pink or red on no more than 10 % of the fruit surface. "Turning" means that 10 to 30 % of the surface shows a definite change in colour similar to breakers. Colour change for green to tannish yellow, pink or red in 30 to 60 % of the tomato surface is considered to be in the "pink" stage. The "light red" stage suggests that 60 to 90 % of tomato surface colour has changed from green to pink or red. The final category called "red" requires the surface of the tomato to be at least 90 % red.

Sunscald was measured on a scale of 0, 1, and 2, where 0 was none, 1 was mild, and 2 was severe sunscald. Cracks and blossom-end rot were only noted if they were present.

According to the USDA (1973), serious damage catfacing are scars which are rough and deep, channels that are very deep and wide, and extend into the locules, or a fairly smooth catfacing with a specific combined circle of more than 0, 6, 13, 19, and 25 mm in diameter (Based on a tomato having a diameter of 64 mm). These specific diameters of 0, 6, 13, 19, 25 mm were represented on a scale from 1 (no damage) to 5 (very severe damage) respectively.

Rainfall, pan evaporation, wind run, maximum and minimum pan water temperature were measured daily during the 1993 and 1994 growing seasons, at the Brace Research Station located on the Macdonald Campus, adjacent to the experimental site.

3.5 Statistical Analysis

A central composite design response surface was chosen instead of a factorial design because not all permutations of the fertilizer treatment levels were examined. In contrast, all combinations of water table depths were employed, thereby preventing the use of a factorial design. Fruit parameters were averaged per plant before analysis, and the percent sunscald and catfacing was converted by the arcsin square root transformation.

Using a response surface program (appendix B), PC-SAS version 6.04 developed coefficients for regression equation. Initially, the matrix did not have all its terms linearly independent. An orthogonal procedure failed to remedy the problem, so it was suggested to remove the least important term, namely the term Ca*Ca. Surfer Version 4.1, calculated the grid plots and drew the contour maps (appendix A). This design can show if water table depth was significant, but no ranking tests (Scheffe's or Duncan's) can be used. Therefore, ranking (i.e. biggest to smallest) the parameters can be accomplished by comparing the range of the parameters within each WTD.

4.0 Results and Discussions

4.1 Meteorological Observations

The climatic data measured was used to estimate the evapotranspiration (ET) of the tomato crop utilizing the pan evaporation method. This method provides a direct measurement of the combined effects of radiation, wind, temperature, and humidity from an open water surface. In a similar manner, the tomato plant responds to the same climatic factors, but several major elements may produce significant differences in water loss. For these reasons the pan evaporation (ET_p) is converted to a reference evapotranspiration (ET_o) by multiplying it by a pan constant (k_p).

$$ET_p * k_p = ET_o \qquad [4.1]$$

The pan constant is influenced by the type of pan used, and the pan's surrounding environment. To correct for these dissimilarities, charts are available (Doorenbos and Pruitt, 1977), but for this research a polynomial solution for k_p (ASCE, 1990) was calculated. A value was computed every day between planting and harvesting, resulting in a range of k_p from approximately 0.67 to 0.82.

$$\begin{gathered} k_p = 0.475 - 0.24*10^{-3}U_d + 0.516*10^{-2}RH_{mean} + 0.118*10^{-2}d \\ -0.16*10^{-4}(RH_{mean})^2 - 0.101*10^{-5}d^2 - 0.8*10^{-8}(RH_{mean})^2 U_d \\ -0.1*10^{-7}(RH_{mean})^2 d \end{gathered} \qquad [4.2]$$

where: k_p = Pan evaporation coefficient

U_d = Mean day wind speed (2 m above ground level)

RH_{mean} = Mean daily relative humidity (%)

d = Fetch distance of green crop (m)

Once the ET_o has been determined, it must then be converted to the estimated evapotranspiration for the tomato plants (ET_c). A crop coefficient (k_c) is used to convert ET_o to ET_c. Different plants have specific water crop coefficients (k_c), and values of k_c are unique to the different stages of plant growth (Table 4.1). To compute ET_c for tomatoes, the reference evapotranspiration is multiplied by k_c according to the specific growth stage of the tomato plant.

$$ET_o * k_c = ET_c \qquad [4.3]$$

Figure 4.1 compares the estimated ET_c with site rainfall, also note that the figure starts at crop growth stage 2 because germination (stage 1) took place before transplanting in the greenhouse.

Table 4.1 Coefficients of Consumptive Use

Crop Growth Stage[†]	Crop Consumptive Use Coefficient (k_c)[‡]
1 (Germination)	0.5
2 (Vegetative)	0.8
3 (Reproductive)	1.15
4 (Fruit development)	0.9
5 (Ripening)	0.65

[†] According to section 2.2.2.
[‡] Values from Doorenbos and Kassam (1979).

Rainfall data from the experimental site was collected and compared with the long term daily averages from 1961 to 1990 which was collected at the Montréal Dorval International Airport, approximately 16 km from the experimental site.

The site rainfall from June 11 to 30, 1993 was 100.5 mm (almost double the long term average of 54.7 mm), while July was 93.2 mm, and August 1 to 23 was 24.9 mm (about one third of the long term average of 71.5 mm) (Table 4.2). June had a surplus soil water status (Rain-ET_c) of 36.2 mm, and July and August each had a deficit of 26 mm. The total rainfall for the 1993 growing season (June 11 to August 23) was within 10 mm of the long term average of 211.8 mm.

Site rainfall during 1994 proved to be quite erratic, with 174.6 mm of rain in June (roughly thrice the long term average of 78.0 mm), 55.7 mm for July, and 46.9 mm for the period of August 1 to 9 (Table 4.3). June and July had soil moisture surpluses of 76.1 and 25.4 mm, respectively, while July produced a deficit of 63.6 mm. The total site rainfall for the 1994 growing season produced an excess of 58.1 mm compared to the 1993 growing season, and 81.9 mm more than the long term average of 194.8 mm.

There was a deficit soil water status relative to ET_c during July and August 1993 (Table 4.2) and July 1994 (Table 4.3) implying a need for irrigation during these months. This can also be seen in Figure 4.1, which shows the actual daily rainfall and estimated crop evapotranspiration for both years of study.

Table 4.2 Rainfall and ET_c for the 1993 growing season at the site.

Month (1993)	1961 to 1990† (mm)	Rain (mm)	Pan ET (mm)	ET_c (mm)	Rain-ET_c (mm)
June 11 to 30	54.7	100.5	99.2	63.8	36.2
July	85.6	93.2	161.2	119.2	-26.0
August 1 to 23	71.5	24.9	89.2	50.6	-25.7
Total	211.8	218.6	349.6	233.6	-15.5

† Collected at Dorval International Airport, approximately 16 km from site

Table 4.3 Rainfall and ET_c for the 1994 growing season at the site.

Month (1994)	1961 to 1990† (mm)	Rain (mm)	Pan ET (mm)	ET_c (mm)	Rain-ET_c (mm)
June	78.0	174.6	145.6	98.5	76.1
July	85.6	55.7	158.1	118.8	-63.1
August 1 to 9	31.2	46.9	33.3	21.4	25.5
Total	194.8	276.7	337.0	238.7	38.5

† Collected at Dorval International Airport, approximately 16 km from site

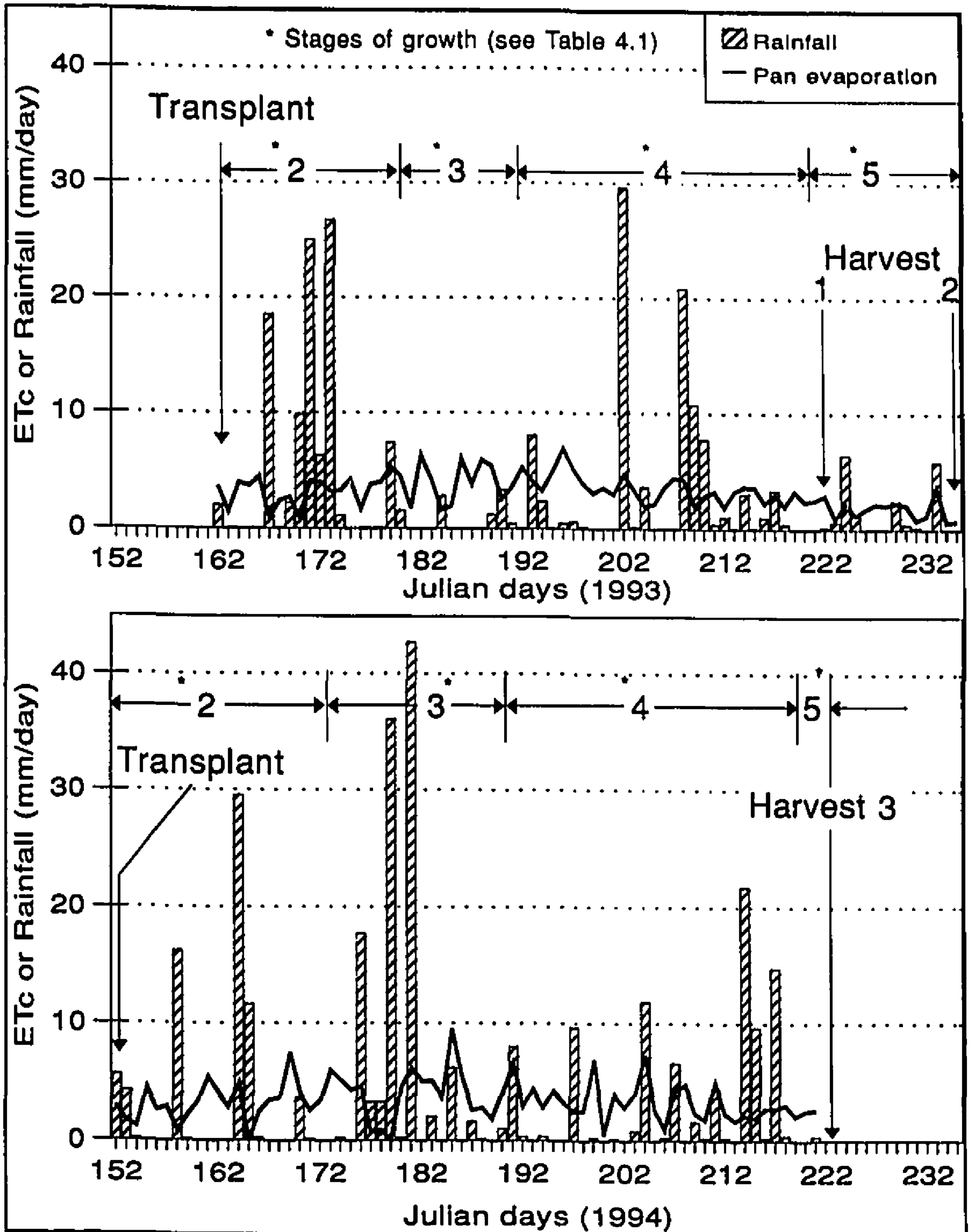


Figure 4.1 Rainfall and ETc

4.2 Soil Fertility

There was a general decrease in concentration of ammonium [NH_4^+], nitrate [NO_3^-], and potassium [K^+] in the soil solution from spring 1993 to autumn 1994 (Figure 4.2).

4.3 Soil Moisture

Soil moisture, measured using TDR, gave a result in percent soil moisture content (v/v). Figure 4.3 displays the average readings at each WTD using 30 cm and 60 cm probes for 1993 and 1994 respectively. Results show that readings taken using the same probe length, generally did not have errorbars which overlapped for 30 and 60 cm WTD, but did for the 80 and 100 cm WTD. Assuming that errorbars represent a confidence interval of 95 %, non-overlapping errorbars show that 95 % of the time, the measurement taken can be considered different.

The actual depths of water tables throughout the growing season for 1993 and 1994 can be found in Figure 4.4, with 95 % confidence intervals. During the growing season each WTD fluctuated, but their difference in depth usually did not narrow, except during the initial setup of each growing season. The errorbars did at no time overlap, demostrating how distinct the water tables remained throughout the growing season. The fluctuations can be attributed to the amount of precipitation.

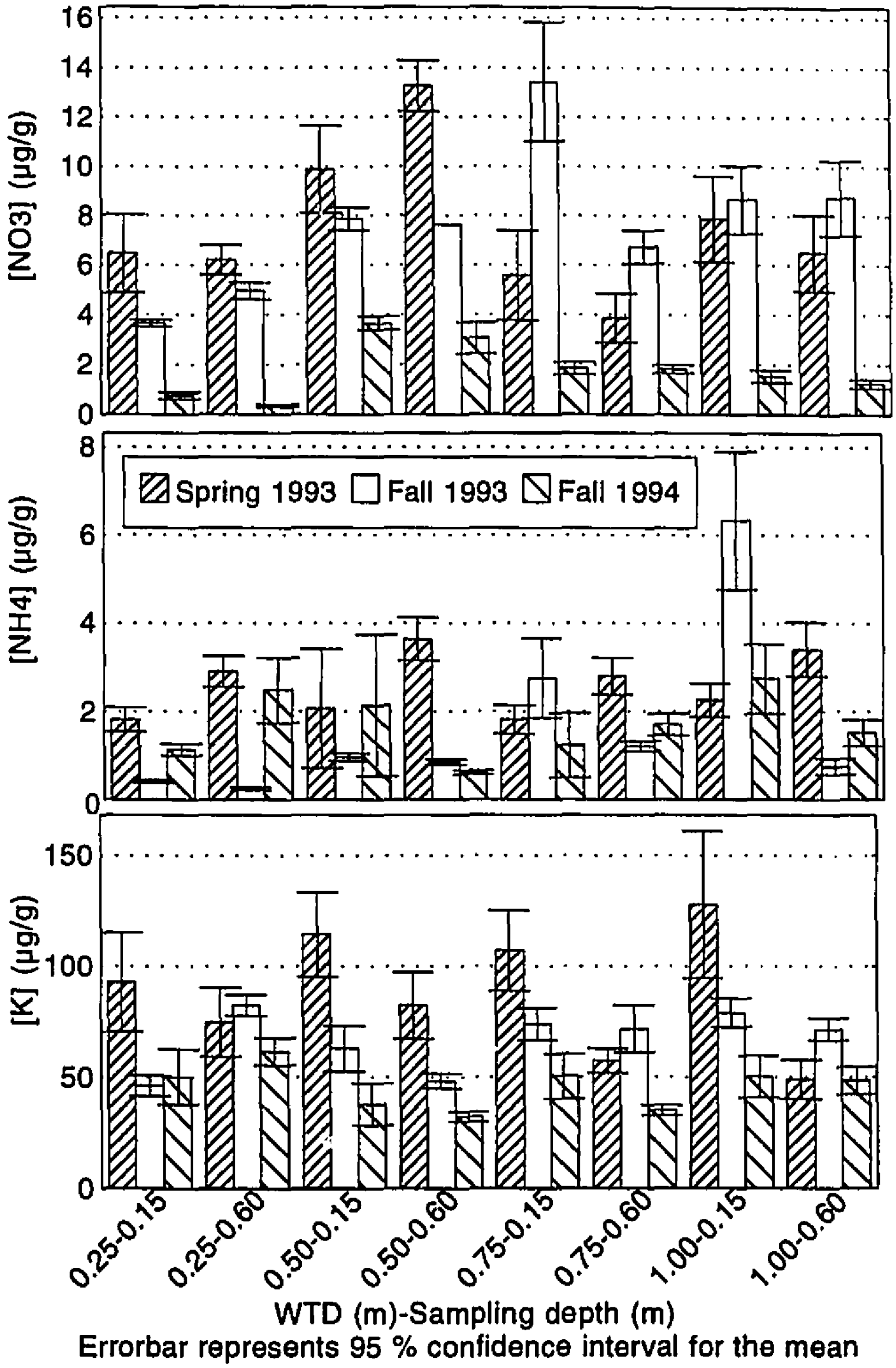
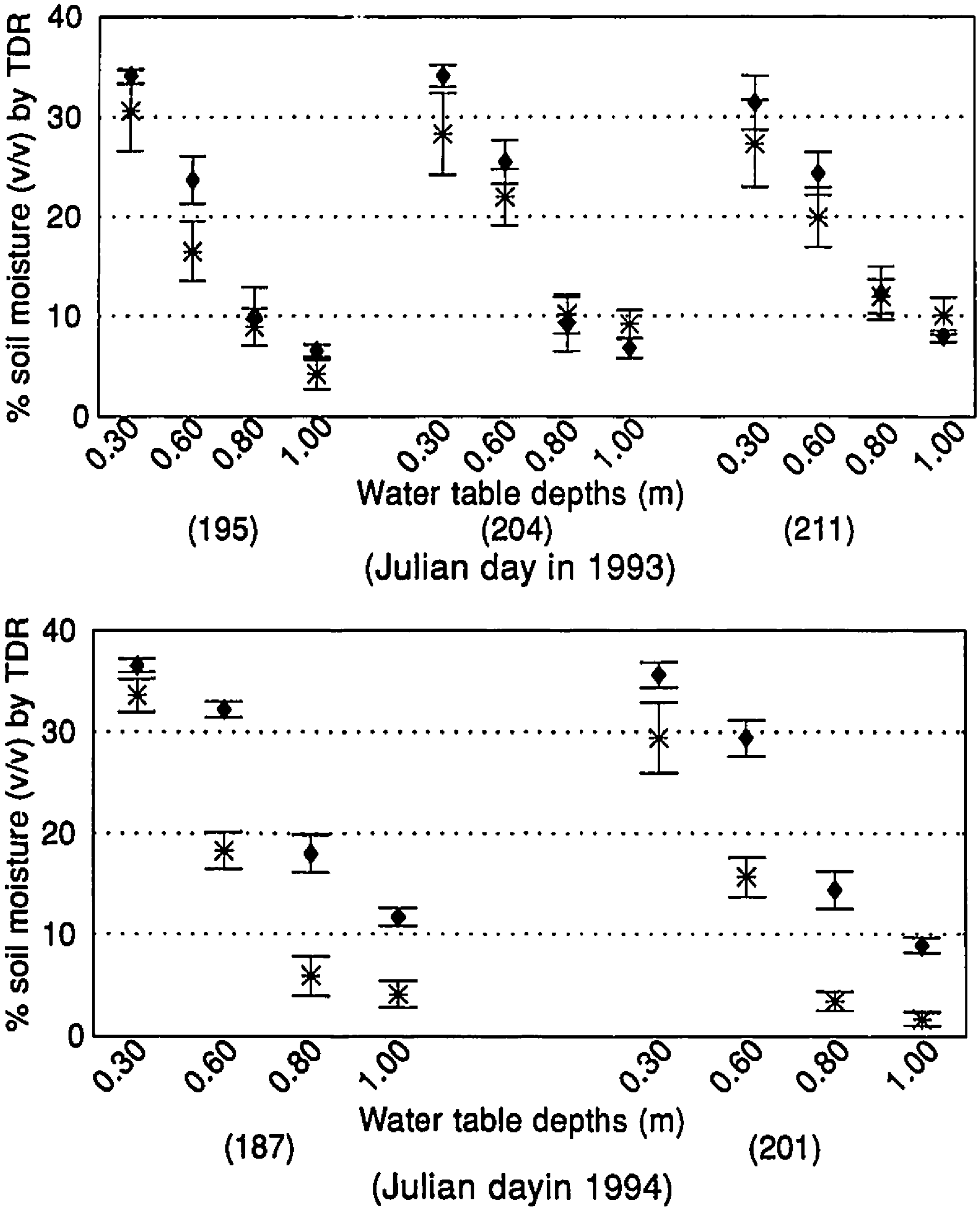
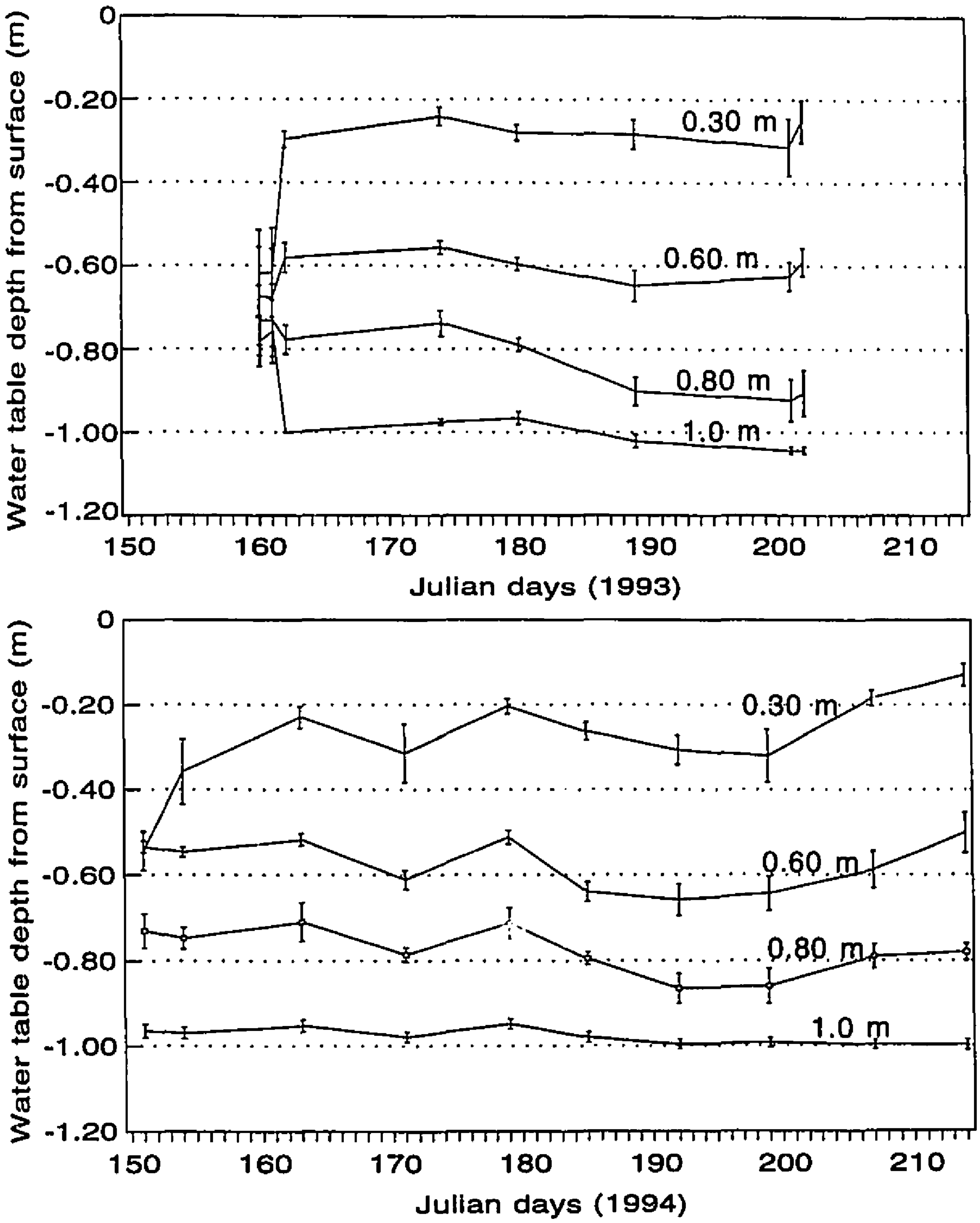


Figure 4.2 Soil fertility results



Errorbar represents 95 % confidence interval for mean

Figure 4.3 TDR results Probe length: * 0.15 m, ♦ 0.60 m



Errorbar represents 95 % confidence interval for the mean

Figure 4.4 WTD measurements

4.4 Plant Parameters

4.4.1 Harvest dates

The total tomatoes harvested on August 9 and 23 in 1993, and August 7 in 1994 have been referred to as Harvest 1, 2, and 3 respectively. All the marketable fruit which met the USDA (1973) standards was found by assessing the three total harvests. The 3 groups of marketable tomatoes harvested have been named Harvest M1, M2, and M3, according to the total harvest which they belong.

4.4.2 Height of fruit

Effects of calcium (Ca) and potassium (K) on the height of tomato fruit by WTD were only significant in the 0.3 m WTD for Harvest 1 (Table 4.4). The response surface for this WTD shows that tomato fruit height for the Harvest 1 peaks at K ≈ 80 kg/ha, and this ridge becomes wider as applied Ca increases (Fig. A1). The marketable tomatoes harvested produced the same peak location, but the opposite effect was noticed with increasing Ca applications (Fig. A4).

The water table depth was highly significant in the first 2 harvests (Table 4.5), and the fruit height was affected by WTD for the total and marketable harvests in such a way that 0.6 m WTD produced the highest tomatoes fruit height followed by 0.3, 0.8, and 1.0 m (Fig. A1 to A6) (Table 4.7 & 4.8). Even though maps for Harvest 1 and Harvest M1 seemed similar, calcium effects were only significant in M1 (Table 4.6), probably because for all WTDs as Ca decreases, so does the height of the fruit (Fig. A1 & A4).

4.4.3 Maximum and minimum equitorial widths

Both widths had similar results as tomato height (Table 4.4), except that the ridge on the response surface remained approximately the same thickness throughout the range of applied Ca (Fig. A7 & A13). Harvest 2 produced significant effects where if Ca and K applied both increased, the widths of the tomato increased (Fig. A8 & A14). A negative effect resulted if, for example, a tomato plant received a low K treatment and a high Ca treatment. Marketable fruit gave the same results as total fruit harvested (Fig. A7 to A18).

Water table depth was highly significant for all three harvests (Table 4.6). Harvest 1 & 2 produced similar results, where the width of the fruit tended to be ranked the same as the tomato height. The range of fruit widths for each WTD of harvest 3 as per the response surfaces and Table 4.7 & 4.8 produced from biggest to smallest were 0.6, 0.8, 1.0, and 0.3 m, respectively (Fig. A7 to A18). Other significant terms were: harvest 1 where K tended to increase the maximum width from 160 to 240 kg/ha (Fig. A7), Ca*K for harvest 2, and K*K for harvest 3.

4.4.4 Degree of catfacing and sunscald

Calcium was the only fertilizer treatment that was significant (Table 4.4) with catfacing, this only in the first harvest and at the 1.0 WTD. The response surface showed that an increase in the total Ca applied,

Table 4.4 Significant terms including Ca and K when analyzing by water table depth

Harvest	Harvest date	WTD (m)	Height	Tomato width (mm)		Degree of		Yield
			(mm)	Maximum	Minimum	Catfacing	Sunscald	Fruit/plt
1		0.30	K^{**} $K*K^{*}$ $Ca*K^{**}$	K^{**} $K*K^{*}$ $Ca*K^{**}$	K^{**} $Ca*K^{**}$	NS	NS	NS
1	August 11	0.60	NS	NS	NS	NS	NS	NS
1	1993	0.80	NS	NS	NS	NS	NS	NS
1		1.00	NS	NS	NS	Ca^{*}	NS	NS
2		0.30	NS	Ca^{*} $Ca*K^{**}$	Ca^{*} $Ca*K^{**}$	NS	Ca^{**}	NS
2	August 23	0.60	NS	NS	NS	NS	NS	NS
2	1993	0.80	NS	NS	NS	NS	NS	NS
2		1.00	NS	NS	NS	NS	Ca^{*} K^{**}	$K*K^{**}$
3		0.30	NS	NS	NS	Ca^{**} K^{*} $Ca*K^{**}$	NS	NS
3	August 9	0.60	NS	NS	NS	NS	$K*K^{**}$	NS
3	1994	0.80	NS	NS	NS	NS	NS	NS
3		1.00	NS	NS	NS	NS	NS	$Ca*K^{**}$

** 5 % level of significance
* 10 % level of significance
NS Not significant to 10 % level

Table 4.5 Significant terms for marketable fruit when analyzing by water table depth

Marketable Harvest	Harvest date	WTD (m)	Height (mm)	Tomato width (mm) Maximum	Tomato width (mm) Minimum	Degree of Catfacing	Degree of Sunscald	Yield Fruit/plt
M1		0.30	K^{**} $K*K^{*}$ $Ca*K^{**}$	K^{**} $K*K^{**}$ $Ca*K^{**}$	K^{**} $K*K^{**}$ $Ca*K^{**}$	NS	N/A	K^{**} $K*K^{**}$ $Ca*K^{**}$
M1	August 11	0.60	NS	NS	NS	NS	N/A	NS
M1	1993	0.80	NS	NS	NS	NS	N/A	NS
M1		1.00	NS	NS	NS	Ca^{**} K^{*}	N/A	K^{**}
M2		0.30	NS	NS	NS	NS	N/A	Ca^{**} K^{**}
M2	August 23	0.60	NS	NS	NS	NS	N/A	NS
M2	1993	0.80	NS	NS	NS	NS	N/A	NS
M2		1.00	NS	NS	NS	NS	N/A	K^{**} $K*K^{**}$
M3		0.30	NS	NS	NS	NS	N/A	NS
M3	August 9	0.60	NS	NS	NS	NS	N/A	$K*K^{**}$
M3	1994	0.80	NS	Ca^{**}	Ca^{**}	NS	N/A	NS
M3		1.00	NS	NS	NS	NS	N/A	NS

M1 refers to marketable fruit from harvest 1
** 5 % level of significance
* 10 % level of significance
NS Not significant to 10 % level
N/A Not applicable (All fruit with sunscald are not marketable (USDA, 1973)

Table 4.6 Significant terms with overall analysis

Harvest	Date	Height	Tomato width (mm)		Degree of		Yield
		(mm)	Maximum	Minimum	Catfacing	Sunscald	Fruit/plt
1	Aug. 11 1993	WTD* WTD*WTD**	WTD* WTD*WTD** K*	WTD* WTD*WTD**	WTD** K** Model*	WTD** WTD*WTD**	WTD** WTD*Ca** WTD*WTD**
2	Aug. 23 1993	WTD** WTD*WTD**	WTD** WTD*WTD** Ca*K**	WTD** WTD*WTD** Ca*K**	K* WTD*Ca** Model*	WTD** K** WTD*Ca** K*K**	WTD** K** WTD*WTD**
3	Aug. 9 1994	NS	WTD** WTD*WTD**	WTD** WTD*WTD** K*K**	WTD*WTD**	WTD*WTD** K*K**	WTD** WTD*WTD**
M1	Aug. 11 1993	WTD** Ca** WTD*WTD** WTD*K*	WTD** WTD*WTD**	WTD** WTD*WTD**	Ca** K** WTD*Ca*	N/A	NS
M2	Aug. 23 1993	WTD** WTD*WTD**	WTD** WTD*WTD** Ca*K**	WTD** WTD*WTD** Ca*K**	NS	N/A	WTD** K** WTD*WTD**
M3	Aug. 9 1994	NS	WTD*WTD** Model*	NS	NS	N/A	WTD** WTD*K** K*K**

M1 refers to the marketable fruit from harvest 1

** 5 % level of significance (Model not mentioned if significant to 5 %)

* 10 % level of significance

NS Model is not significant to 10 %

N/A Not applicable (All fruit with sunscald are not marketable (USDA, 1973))

Table 4.7 Averages and standard deviation of fruit parameters

Harvest	Date	WTD (m)	Height (mm)	Tomato width (mm)		Degree of	
				Maximum	Minimum	Catfacing	Sunscald
1		0.3	50.6±2.2	67.4±4.5	62.7±3.5	0.32±0.20	0.23±0.16
1	August 11 1993	0.6	51.3±1.8	68.7±4.2	62.7±3.5	0.22±0.25	0.12±0.20
1		0.8	49.2±2.8	62.4±5.2	58.6±5.0	0.16±0.20	0.04±0.12
1		1.0	45.3±1.9	57.0±3.0	53.4±2.8	0.21±0.25	0.11±0.13
2		0.3	46.0±1.9	62.8±2.4	56.8±2.2	0.64±0.36	0.40±0.18
2	August 23 1993	0.6	47.3±1.5	65.3±3.5	58.9±2.9	0.60±0.32	0.37±0.19
2		0.8	44.2±3.9	58.2±4.8	52.6±4.1	0.79±0.23	0.46±0.20
2		1.0	37.4±2.8	48.1±3.8	43.5±3.2	0.66±0.34	0.51±0.29
3		0.3	40.6±4.2	47.9±5.9	44.4±4.4	0.30±0.31	0.33±0.40
3	August 9 1994	0.6	41.3±2.8	55.7±5.2	50.0±3.6	1.08±0.51	0.62±0.30
3		0.8	39.2±2.3	54.1±2.5	49.2±2.4	0.55±0.32	0.33±0.22
3		1.0	40.6±2.9	51.3±3.1	47.0±2.6	0.51±0.25	0.31±0.26

Table 4.8 Averages and standard deviation of marketable fruit parameters

Harvest	Date	WTD (m)	Height (mm)	Tomato width (mm) Maximum	Tomato width (mm) Minimum	Degree of Catfacing	Degree of Sunscald
M1		0.3	50.5±2.4	66.5±3.9	62.4±3.2	0.32±0.17	0
M1	August 11 1993	0.6	51.3±1.9	68.0±3.5	63.7±2.8	0.21±0.23	0
M1		0.8	49.4±2.7	62.0±5.0	58.4±4.7	0.16±0.19	0
M1		1.0	45.4±2.2	57.0±2.8	53.4±2.8	0.21±0.25	0
M2		0.3	45.3±1.5	60.1±2.4	55.1±2.4	0.55±0.26	0
M2	August 23 1993	0.6	46.8±1.6	62.9±3.1	57.7±2.8	0.53±0.26	0
M2		0.8	44.0±3.7	55.6±4.7	51.3±4.3	0.68±0.19	0
M2		1.0	38.2±2.9	46.9±4.3	43.4±3.9	0.58±0.29	0
M3		0.3	41.4±4.5	48.1±4.0	44.7±3.2	0.16±0.22	0
M3	August 9 1994	0.6	39.8±4.6	51.1±6.1	46.9±5.1	0.41±0.33	0
M3		0.8	38.7±2.8	52.2±3.5	47.7±3.3	0.25±0.17	0
M3		1.0	39.4±3.1	48.3±3.6	45.1±2.7	0.22±0.14	0

M1 is marketable fruit from harvest 1

increased the degree of catfacing (Fig. A19). Marketable fruit showed K as being significant in Harvest 1 at 0.3 m WTD, where an increase in K decreased catfacing (Fig. A22). Calcium and potassium were both significant in Harvest 3 at a WTD of 0.3 m. In this case catfacing was lowest at 0 kg/ha of Ca with a range of K between 80 and 240 kg/ha, but increased as the treatment of K decreased and Ca increased (Fig. A21).

Analyzing catfacing by harvest revealed a highly significant model only in Harvest 3, and in the first two only at a significance of 10 % (Table 4.6). In Harvest 1 water table and K were significant; from Figure A19, 0.3, 0.6, 1.0 m showed that with more K, catfacing will decrease, and 0.3 and 1.0 m revealed that at approximately 160 kg/ha of K, the slope for catfacing dramatically increased as K decreased. Table 4.6 shows that for Harvest 2 K and the bi-linear term WTD*Ca were significant and WTD*WTD was significant for Harvest 3.

Only harvest 2 and 3 had significant K and Ca parameters for sunscald (Table 4.4). For Harvest 2 and a WTD of 0.3 m, as Ca increases, so does the degree of sunscald (Fig. A26). At 1.0 m WTD, K tends to control the degree of sunscald from 0 to 200 kg/ha, decreasing the sunscald as K increases; from 200 to 400 kg/ha of K, Ca seems to play a significant role where increasing Ca reduces sunscald. In Harvest 3 and 0.6 m WTD, the sunscald increases to a peak from 160 to 240 kg/ha of K, and drops rapidly on both sides of the peak (Fig. A27).

Water table depths were significant for all three harvests (Table 4.6). Significant terms also included K, WTD*Ca, and K*K for Harvest 2, and K*K for Harvest 3.

4.4.5 Yield

The fertilizer treatments were significant in Harvest 2 and Harvest 3 at the 1.0 m WTD (Table 4.4). K increased yield to a peak at approximately 170 to 260 kg/ha for Harvest 2 (Fig. A29). Increasing Ca and K tended to increase the number of fruit per plant. Marketable fruit exhibited significant Ca and K terms in the 0.3 and 1.0 m WTD for Harvest M1 and M2 (Table 4.5). In Harvest M1, for 0.3 m WTD, a ridge formed from 250 to 340 kg/ha of K applied and widened as the total Ca applied was increased; for 1.0 m yield increased as K was increased (Fig. A31). Harvest M2, 0.3 m WTD (Fig. A32) treatment showed an increase in yields as K increased and Ca decreased; the 1.0 m WTD produced a peak for yield at approximately 280 kg/ha of K. Finally, Harvest M3 with 0.6 m WTD shows the lowest yields at 240 kg/ha, but on either side of this value the yield increases with steep slopes (Fig. A33).

Statistical analysis of the overall experiment showed WTD was a highly significant term for the yield of all three harvests (Table 4.6). The best to worst yield for Harvest 1 & 2 were 0.6, 0.3, 0.8, and 1.0 m (Fig. A28 & A29); and for Harvest 3 were 1.0, 0.6, 0.8, and 0.3 m (Fig. A30) (Table 4.7 & 4.8). Figure A29

& A32 show that an increase in of K for Harvest 2 and M2 increased the number of fruit per plant for all WTD treatments except the 1.0 m. Other significant terms were WTD*Ca for Harvest 1, and WTD*K and K*K for Harvest M3. Table 4.9 shows that the total number of tomatoes was lower in

Table 4.9 Average total and marketable harvests

Year Harvested	WTD (m)	Total Yield (fruit/plant)	Marketable Yield (fruit/plant)	Percent Marketable (%)
	0.3	48.1	31.6	65.7
1993	0.6	59.3	39.8	67.2
	0.8	34.5	23.3	67.5
	1.0	23.2	16.8	72.2
	0.3	6.3	3.8	60.3
1994	0.6	19.6	7.8	39.9
	0.8	16.8	11.2	66.5
	1.0	20.5	12.8	62.4

the final year of study. The total yield from 1993 to 1994 dropped by 87, 67, 51.3, and 11.6 % for 0.3, 0.6, 0.8, and 1.0 m WTD. This shows that the deeper the WTD in 1994, the higher the percent total yield as compared to 1993. The percent of fruit which was marketable decreased by as much as 10 % from the first to the second year for all WTD treatments except 0.6 m, which dropped from 67.1 % to 39.9 %. One of the main climatic differences between the two years was the very wet conditions in June 1994. This first month after transplanting should have been characterized by the development of a root system and above ground vegetative growth. Higher water tables could have stunted root growth effectively reducing the root area for mineral absorption. The total yield of fruit per plant tended to decrease from the first to second year by about 12 % for 1.0 m WTD to as high as 87 % for 0.3 m WTD. These loss in total yield could be attributed to erratic and high precipitation, and also because tomatoes need to be rotated with other crops (Johnston, 1992).

4.4.6 Weight and height of plant stem

In order to evaluate the performance of plant growth using different treatments, the weight and height of the plant stem were measured. Results show that the WTD was significant for stem weight during both years of the study, while K was significant for the first year only (Table 4.10). Stem height, on the other hand, had no significant terms, probably because of the erratic nature in which the multiple stems grow making it difficult to measure the plants length. A more in depth investigation of stem weight showed that 0.6 m WTD produced the heaviest stems, while the extreme WTDs (0.3 & 1.0 m) fluctuated from 2nd heaviest to producing the lightest stem weight (Fig. 4.4). This trend could be revealing that the stem's growth is more sensitive to environmental changes when presented with extreme WTD conditions.

Table 4.10 Significant stem weight and height parameters

Year Harvested	Weight	Height
1993	WTD** K** WTD*WTD**	NS
1994	WTD** WTD*WTD**	N/A

** Significant to 5 % level
NS Not significant to 10 % level
N/A Not available

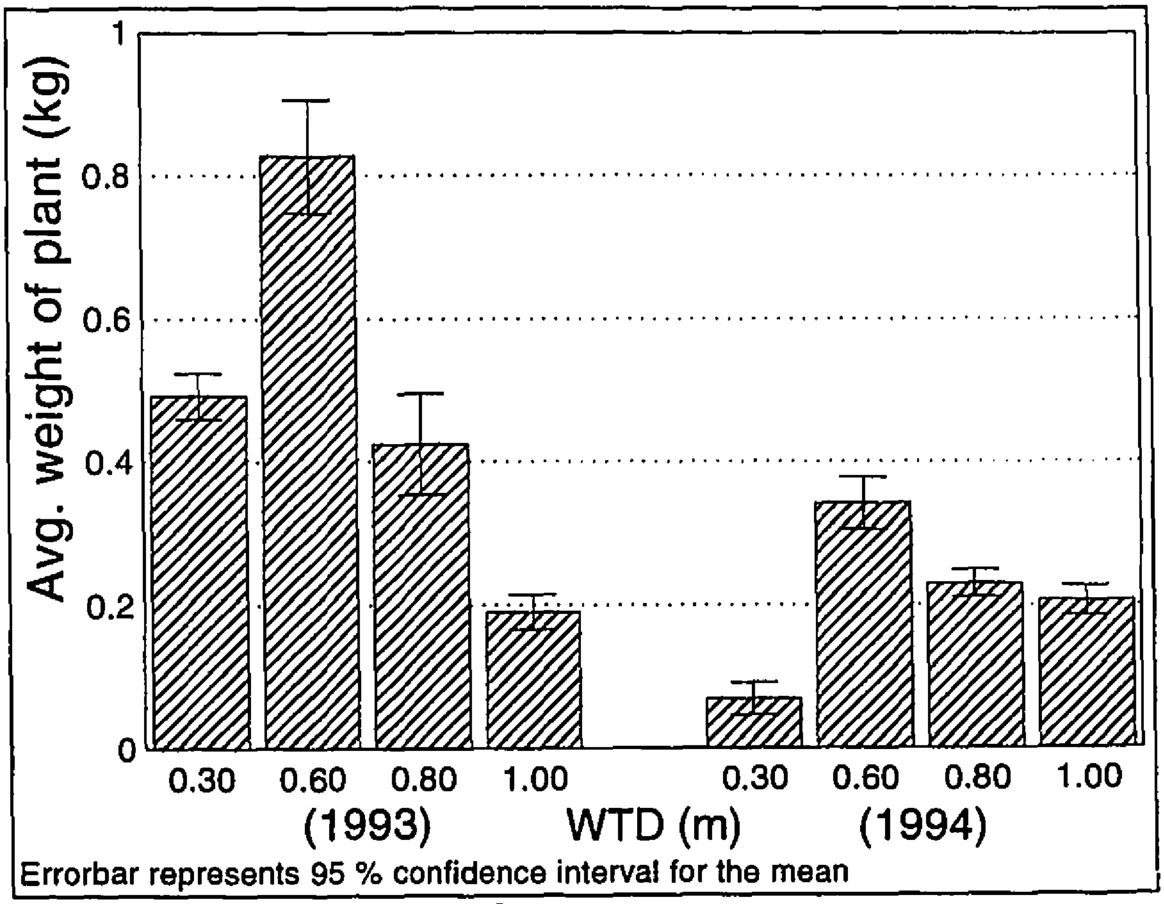


Figure 4.5 Tomato stem weight

4.5 Overall Results

The growing season rainfall for 1994 was 26.6 % or 58.1 mm higher than in 1993. During 1993, the rainfall was evenly distributed over June and July, while in 1994 these months experienced very erratic rainfall. The majority of the 1994 rain fell in June (174.6 mm), which created very wet field conditions. The excess rainfall during the plant's developmental stage, probably retarded root growth especially for the shallow water table depth treatments.

The soil sample results indicate a general decline of NO_3^-, NH_4^+, and K^+ concentrations from the beginning to the end of the study. Soil moisture content tended to decrease as the water table depth increased, and the actual WTD measurements seemed to show four distinct water tables throughout the study period.

Water table depth had a significant effect for all of the total harvests except for tomato height (Harvest 3) and stem height. The optimum water table depth is probably between 0.6 and 0.8 m. This range of WTD consistently produced the biggest tomatoes (according to height and width) and the highest yields. Although the effects of WTD on catfacing and sunscald were significant, they did not remain consistent for both years of study. During the first year, the WTD ranked from lowest to highest degree of catfacing were 0.6, 0.8, 0.3, and 1.0 m; but during the 2nd year, the reverse occurred. None of the water table levels had a diminishing effect on sunscald.

While the fertilizer treatments were sometimes significant, they did not show a consistent trend for all 3 harvests. Generally tomato height and width seemed to peak at approximately 80 kg/ha of K applied with little effect from Ca fertilizer. Yield tended to increase with a rise in applied K and Ca, but potassium appears to have greater influence. Generally the degree of catfacing seemed to be increase with the addition of Ca, and decreased through supplementing K. Also if K is below 160 kg/ha with 0.3 and 1.0 m WTD, then there was a severe increase in catfacing. Calcium had little effect on sunscald when K was below 200 kg/ha, but played a greater role when K was applied in a range of 200 to 400 kg/ha. When Ca has a greater effect, it tends to increase sunscald. With K applications below 200 kg/ha, potassium tended to reduces the degree of sunscald at 0.3 and 1.0 m WTD. At 0.6 m WTD, sunscald peaks at approximately 200 kg/ha of K, and appears to drop drastically on either side of the peak. The significance of 160 kg/ha of potassium fertilizer has also been documented as the recommended fertilizer rate for tomato production by the Conseil des Productions Végétales du Québec (CPVQ, 1978).

The effects of the fertilizer treatments by water table depth seemed to be significant most of the time when the water tables were kept at their extremes (0.3 & 1.0 m). At these conditions the plant may be water stressed, possibly inhibiting root growth. Smaller and fewer roots will have a restricted absorption area, therefore the more nutrients available in the shallower root zone, the better the chance the roots can meet the plant's nutrition requirements.

Plant stem measurements revealed that WTD proved to be a consistently significant parameter, with 0.6 m WTD producing the heaviest stem, and 0.3 and 1.0 m WTD alternating both years for lightest plant stem.

5.0 SUMMARY AND CONCLUSIONS

5.1 Summary

An experiment involving water table management and fertilizer treatments of calcium and potassium was performed at the Horticultural Research Station, Macdonald Campus of McGill University. This study was conducted during the summers of 1993 and 1994 using lysimeters to test the effects of water table depths and fertilizer treatments on tomatoes grown in a sandy loam soil.

The experimental setup included 80 lysimeters evenly divided into four water table groups of 0.3, 0.6, 0.8, and 1.0 m depths. The potassium was added at three levels (0, 160, 400 kg/ha using 0-0-20 K_2O) to each lysimeter at transplanting. Calcium was administered using a foliar spray (1.0 % (w/v) $CaCl_2$), and was applied in three levels ((0 kg/ha), once every two weeks (1500 kg/ha), every week (2500 kg/ha)).

Throughout the growing season, water table level and moisture content were assessed. Plant parameters measured at harvest were tomato yield, maximum and minimum width, degree of catfacing and sunscald, and yield. The weight and height of the plant stems were also measured.

5.2 Conclusions

1. Water table depth proved to be highly significant for tomato height, width, catfacing, sunscald, and yield. The suggested optimum WTD for tomato

height, width, and yield is between 0.6 and 0.8 m. The degree of catfacing was diminished using 0.6 m WTD in the first year, but increased the degree of catfacing in the 2nd year.

2. Fertilizer treatments were rarely significant by water table depths, but when they were, it was usually in the shallowest or deepest water table treatment. The need for good soil-water conditions overshadowed the lack or excess of the fertilizer treatments. Generally, potassium had the greatest fertilizer effect.

2.1. The size of tomato tended to peak at a field application of approximately 80 kg/ha of K. From the two fertilizer treatments, potassium seemed to have the greatest influence on tomato height and width.

2.2. Tomato yield appeared to increase with more K and Ca added, although potassium tended to have the largest effect.

2.3. Catfacing has the tendency to increase with more Ca, and decrease with K. Below 160 kg/ha of potassium, results in a dramatic increase in catfacing when the plant is experiencing extreme WTD (0.3 & 1.0 m).

2.4. Generally sunscald was significantly effected by fertilizer treatments at extreme water table treatments; where K tended to control sunscald from 0 - 200 kg/ha of K, and Ca appeared to have the greatest influence when K was applied at a rate of 200 to 400 kg/ha.

3. Overall, avoiding overly shallow and deep WTD (0.3 & 1.0 m), and fertilizing with 160 kg/ha of K can improve quality and the total yield of tomatoes.

6.0 RECOMMENDATIONS FOR FUTURE RESEARCH

1. Since research has shown plant water requirements change according to its stage of growth, altering the water table depth to meet the growth of each stage could prove beneficial.

2. Incorporating continuous culture and field rotation with controlled WTD can possibly provide better yields and fruit quality.

3. Using various tomato varieties known to respond positively to irrigation, determine which variety will best benefit and at what WTD.

4. Implement a water table management field study with tomatoes, to examine some field problems, and develop practices which the farmer can implement.

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Appendix A

Response surface mapping for parameters

List of Figures in Appendix A

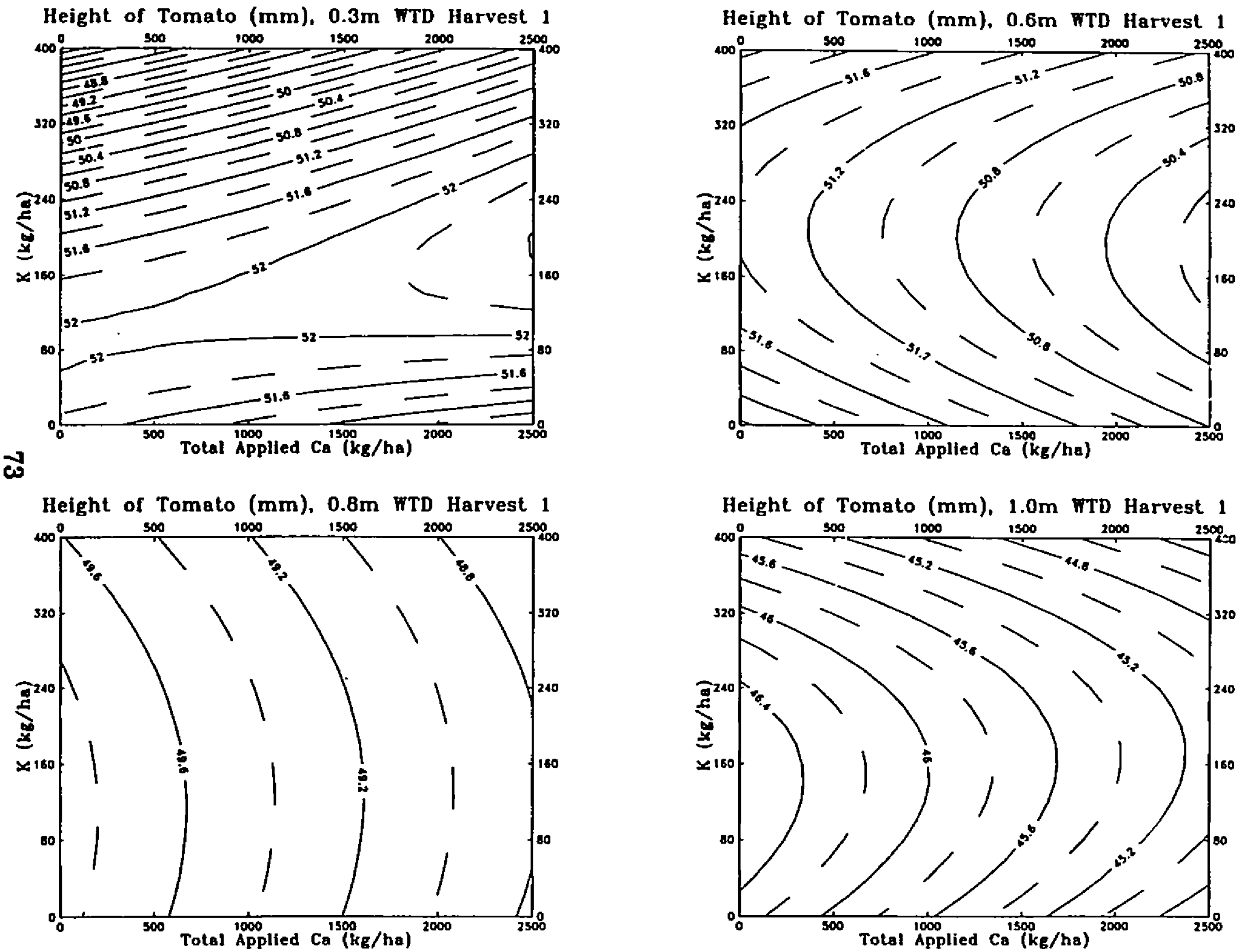
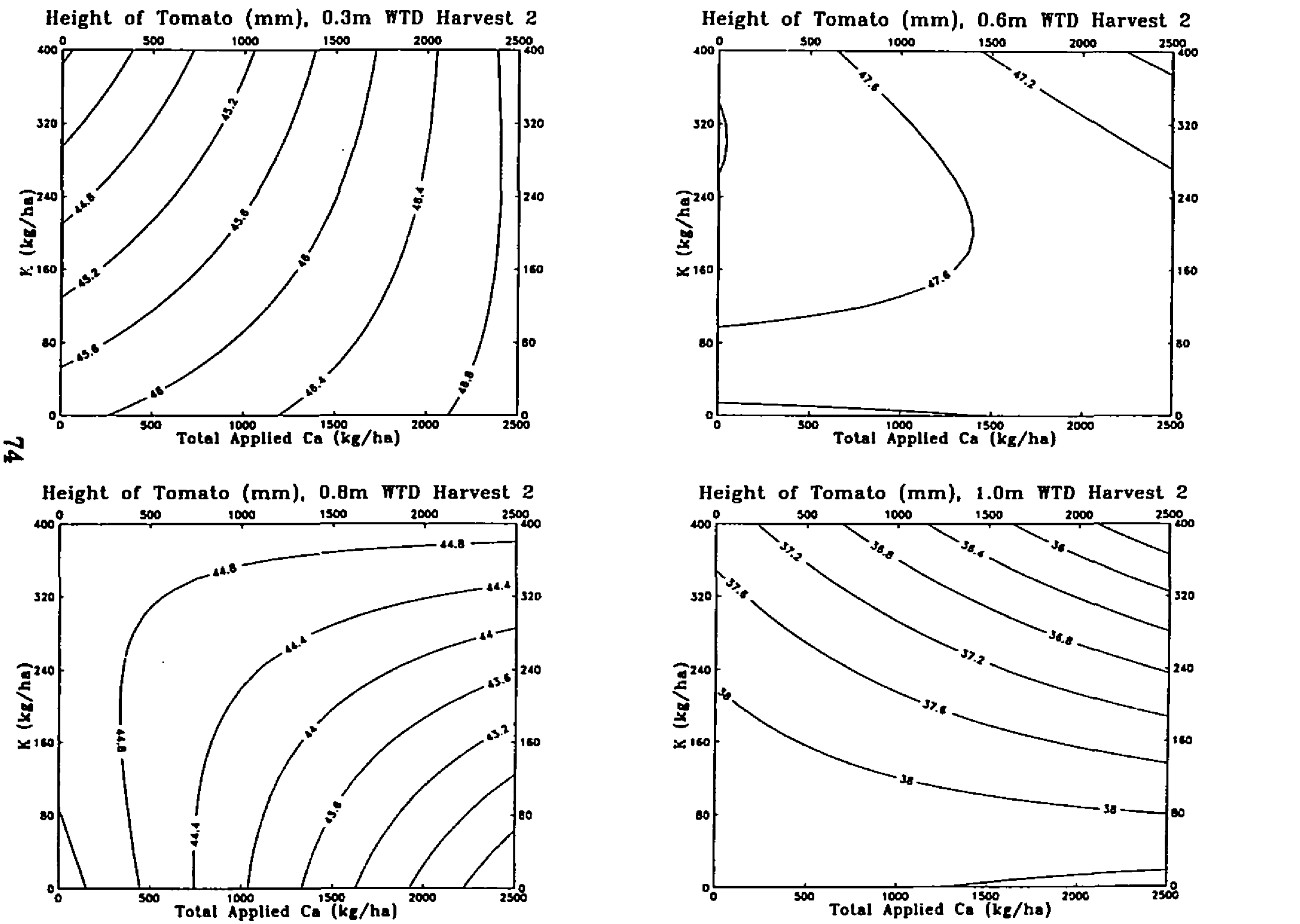

Height of Tomato (mm), 0.3m WTD Harvest 1
Height of Tomato (mm), 0.6m WTD Harvest 1
Height of Tomato (mm), 0.8m WTD Harvest 1
Height of Tomato (mm), 1.0m WTD Harvest 1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A1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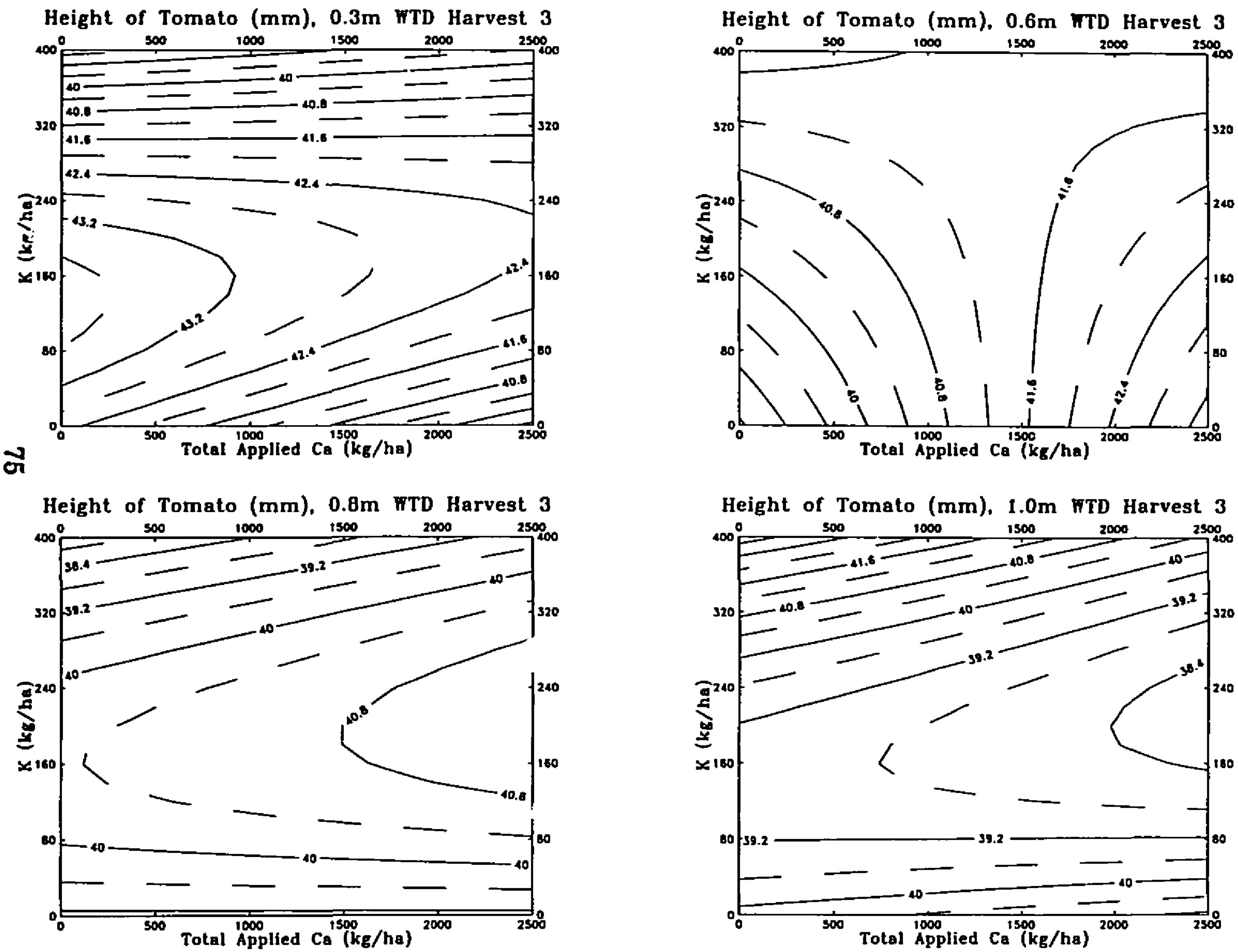
Height of Tomato (mm), 0.6m WTD Harvest 2
Height of Tomato (mm), 0.8m WTD Harvest 2
Height of Tomato (mm), 1.0m WTD Harvest 2
K (kg/ha)
Total Applied Ca (kg/ha)
0
500
1000
1500
2000
2500
80
160
240
320
400
43.2
44.8
45.2
45.6
46
46.4
46.8
47.2
47.6
44
44.4
43.6
37.2
36.8
36.4
36
37.6
38

Figure A2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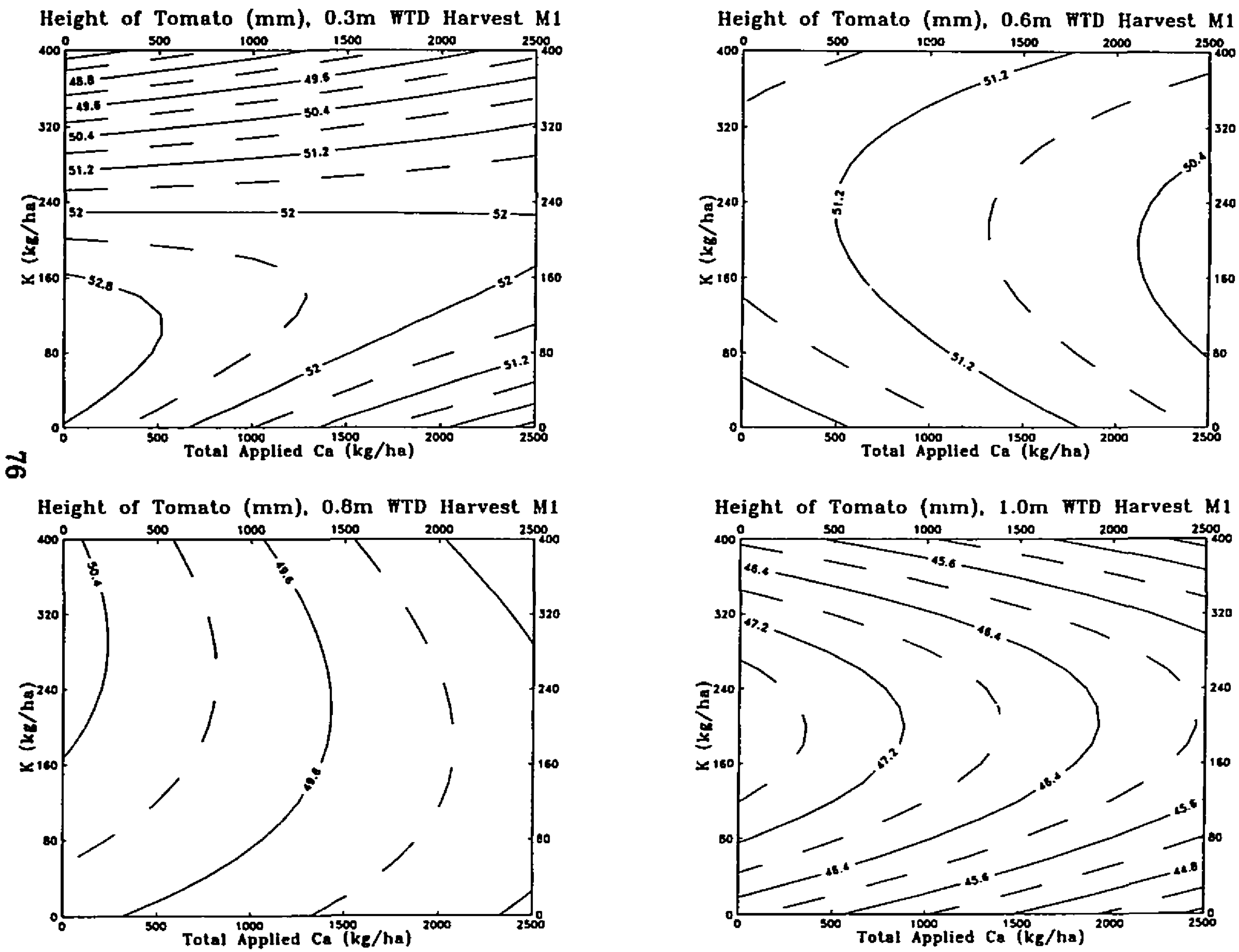
Height of Tomato (mm), 0.6m WTD Harvest 3
Height of Tomato (mm), 0.8m WTD Harvest 3
Height of Tomato (mm), 1.0m WTD Harvest 3
K (kg/ha)
Total Applied Ca (kg/ha)
0
500
1000
1500
2000
2500
80
160
240
320
400
38.4
39.2
40
40.8
41.6
42.4
43.2

Figure A3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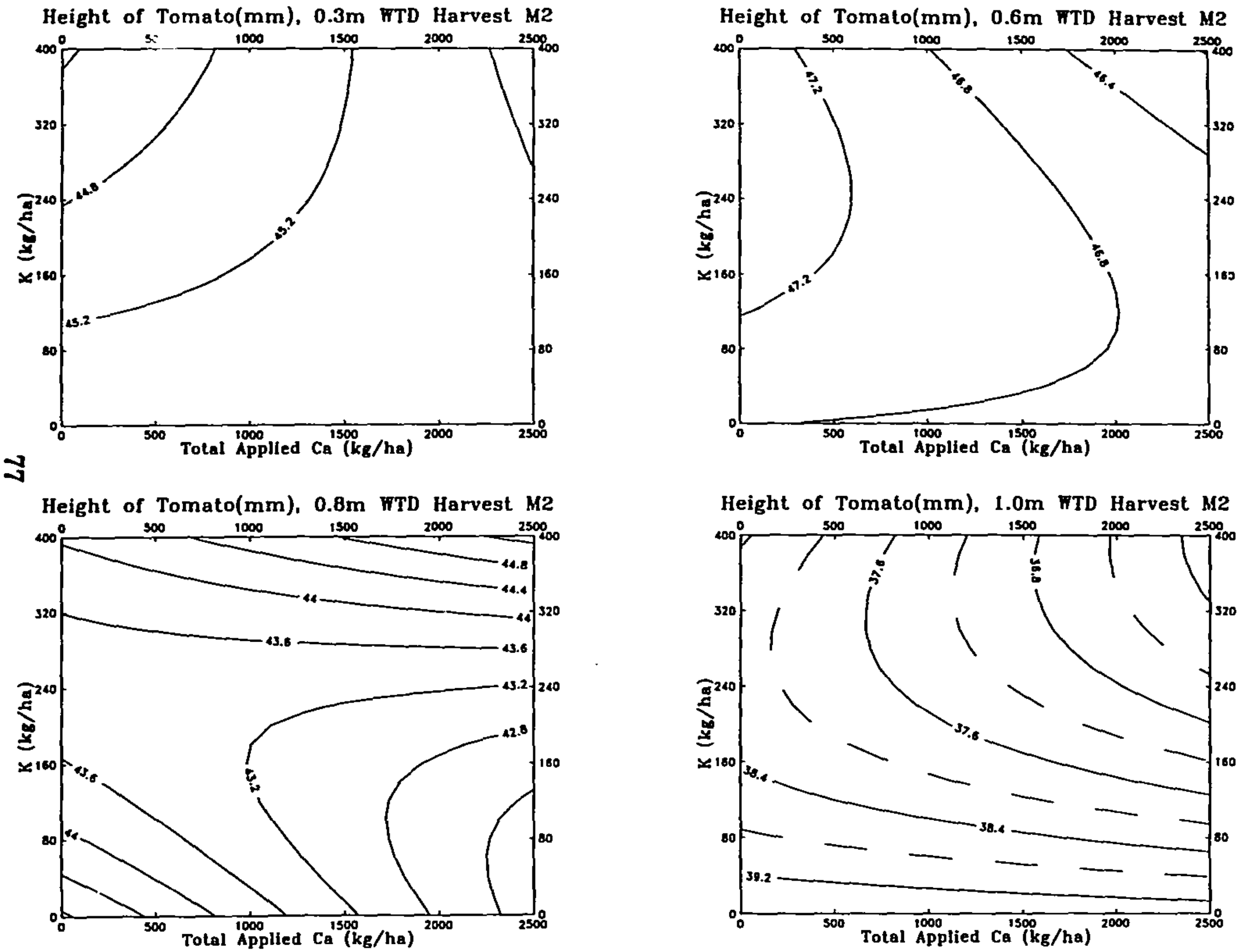
Height of Tomato (mm), 0.6m WTD Harvest M1
Height of Tomato (mm), 0.8m WTD Harvest M1
Height of Tomato (mm), 1.0m WTD Harvest M1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A4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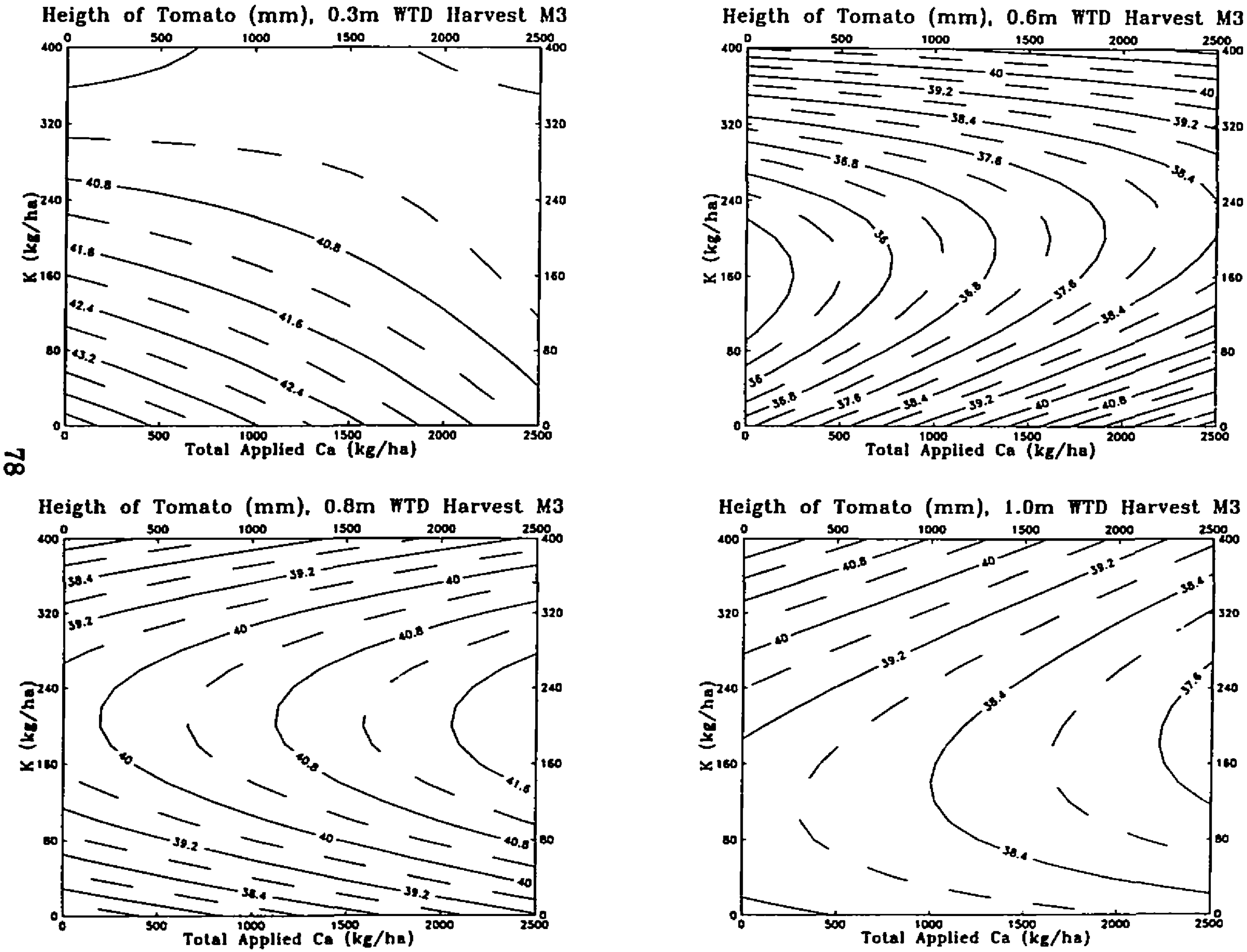
Height of Tomato(mm), 0.6m WTD Harvest M2
Height of Tomato(mm), 0.8m WTD Harvest M2
Height of Tomato(mm), 1.0m WTD Harvest M2
K (kg/ha)
Total Applied Ca (kg/ha)
0
500
1000
1500
2000
2500
80
160
240
320
400
44.8
45.2
47.2
46.8
46.4
44
43.6
43.2
42.8
44.4
37.6
36.8
38.4
39.2

Figure A5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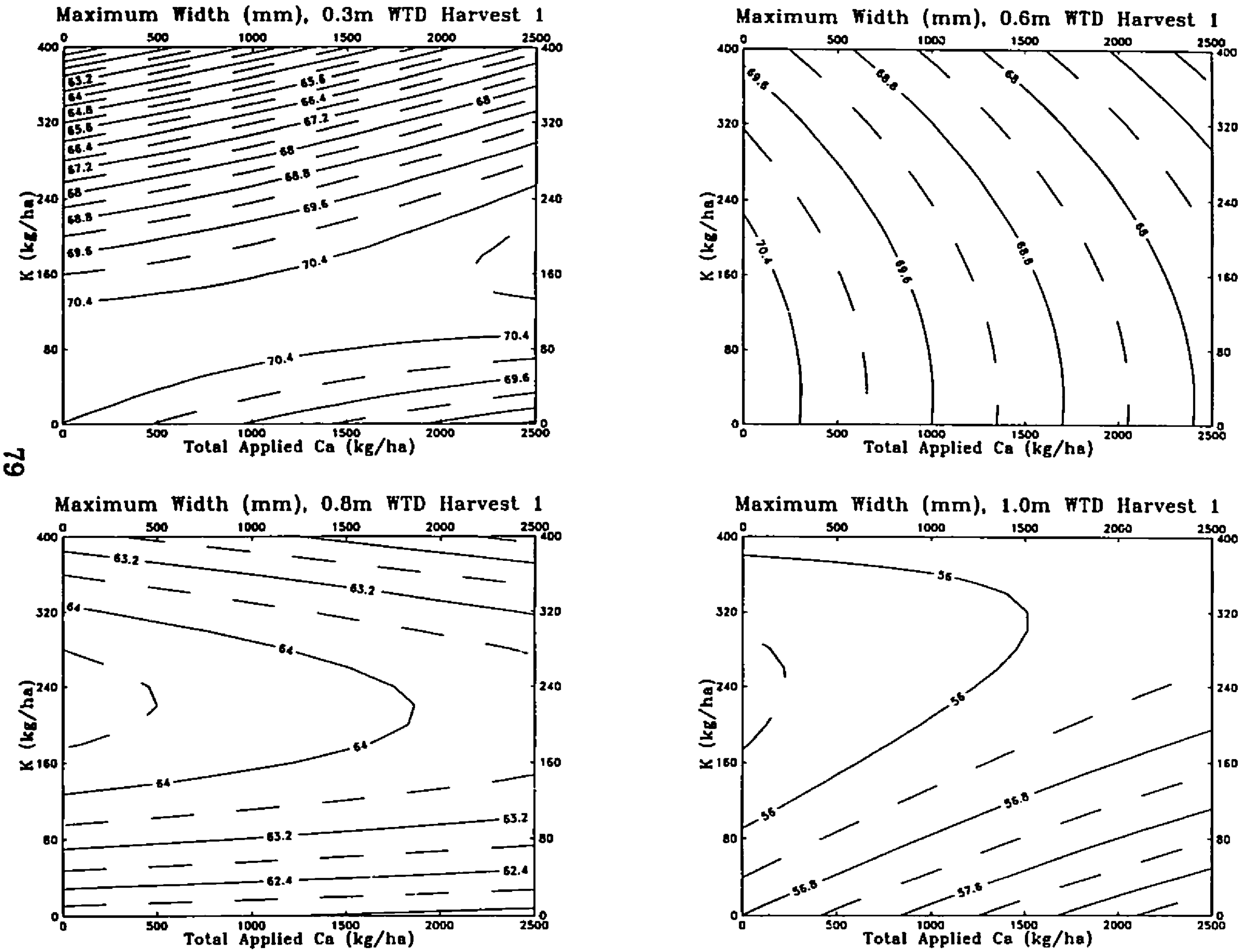
Heigth of Tomato (mm), 0.6m WTD Harvest M3
Heigth of Tomato (mm), 0.8m WTD Harvest M3
Heigth of Tomato (mm), 1.0m WTD Harvest M3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A6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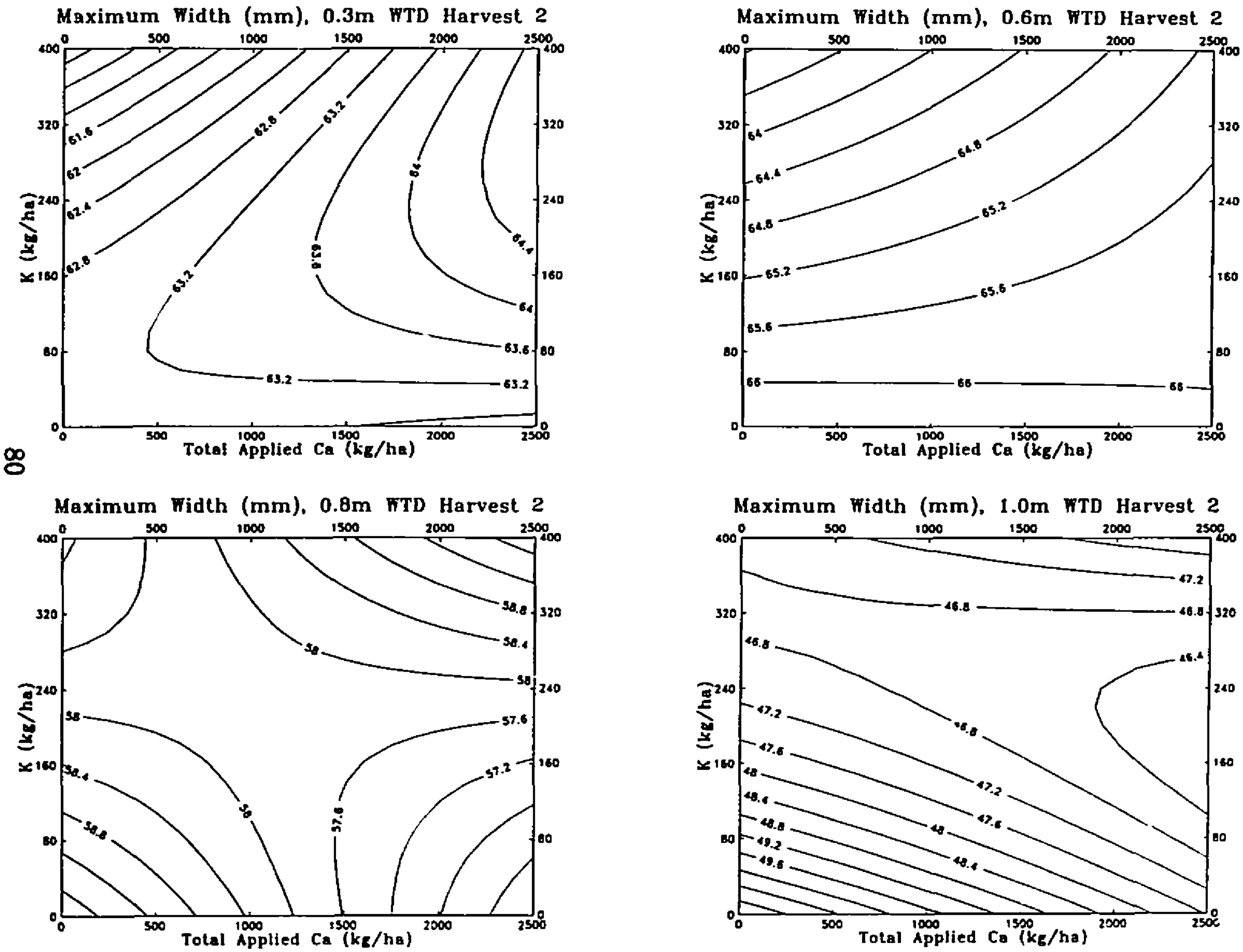
Maximum Width (mm), 0.6m WTD Harvest 1
Maximum Width (mm), 0.8m WTD Harvest 1
Maximum Width (mm), 1.0m WTD Harvest 1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A7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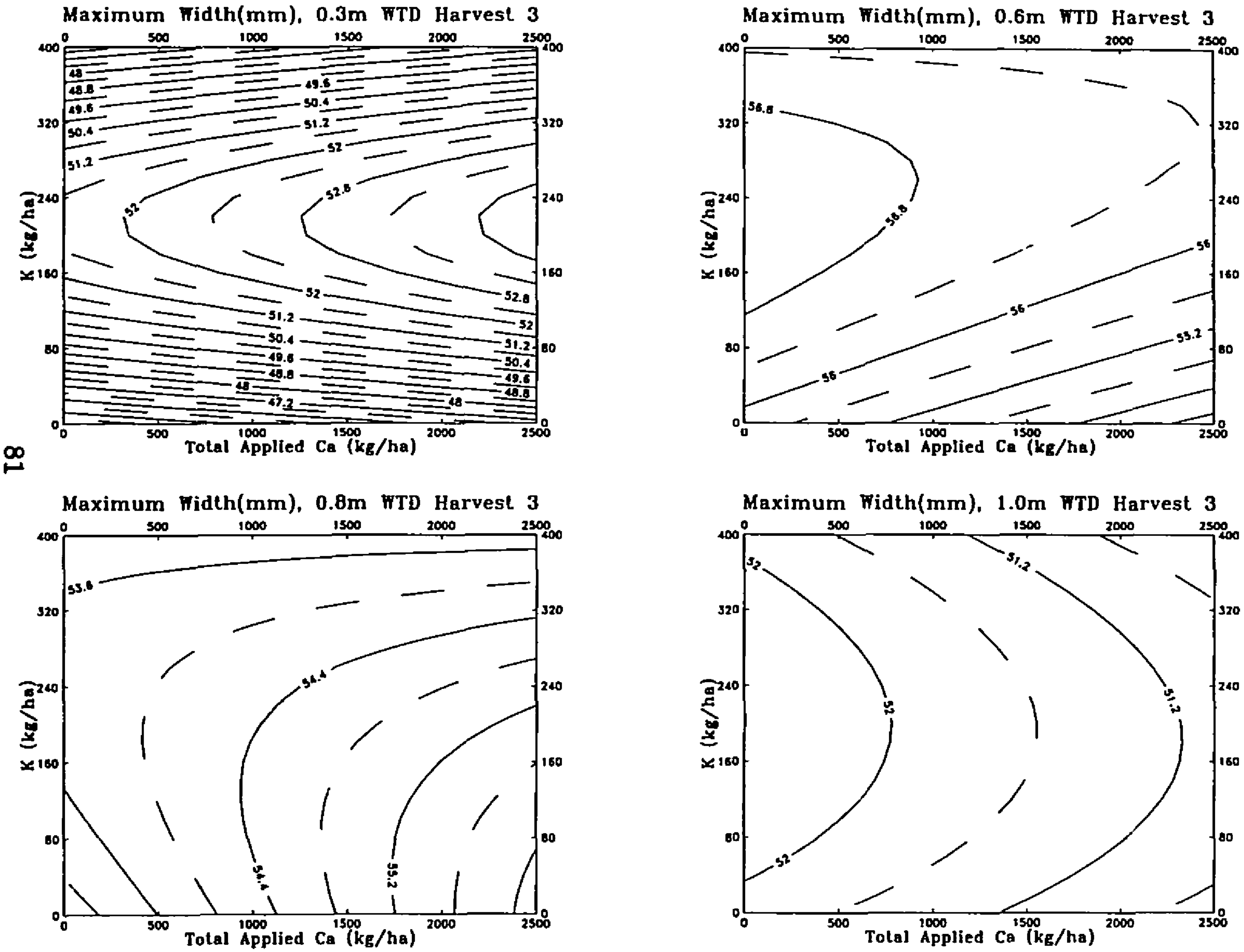
Maximum Width (mm), 0.6m WTD Harvest 2
Maximum Width (mm), 0.8m WTD Harvest 2
Maximum Width (mm), 1.0m WTD Harvest 2
K (kg/ha)
Total Applied Ca (kg/ha)
0
500
1000
1500
2000
2500
80
160
240
320
400

Figure A8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Maximum Width(mm), 0.6m WTD Harvest 3
Maximum Width(mm), 0.8m WTD Harvest 3
Maximum Width(mm), 1.0m WTD Harvest 3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A9

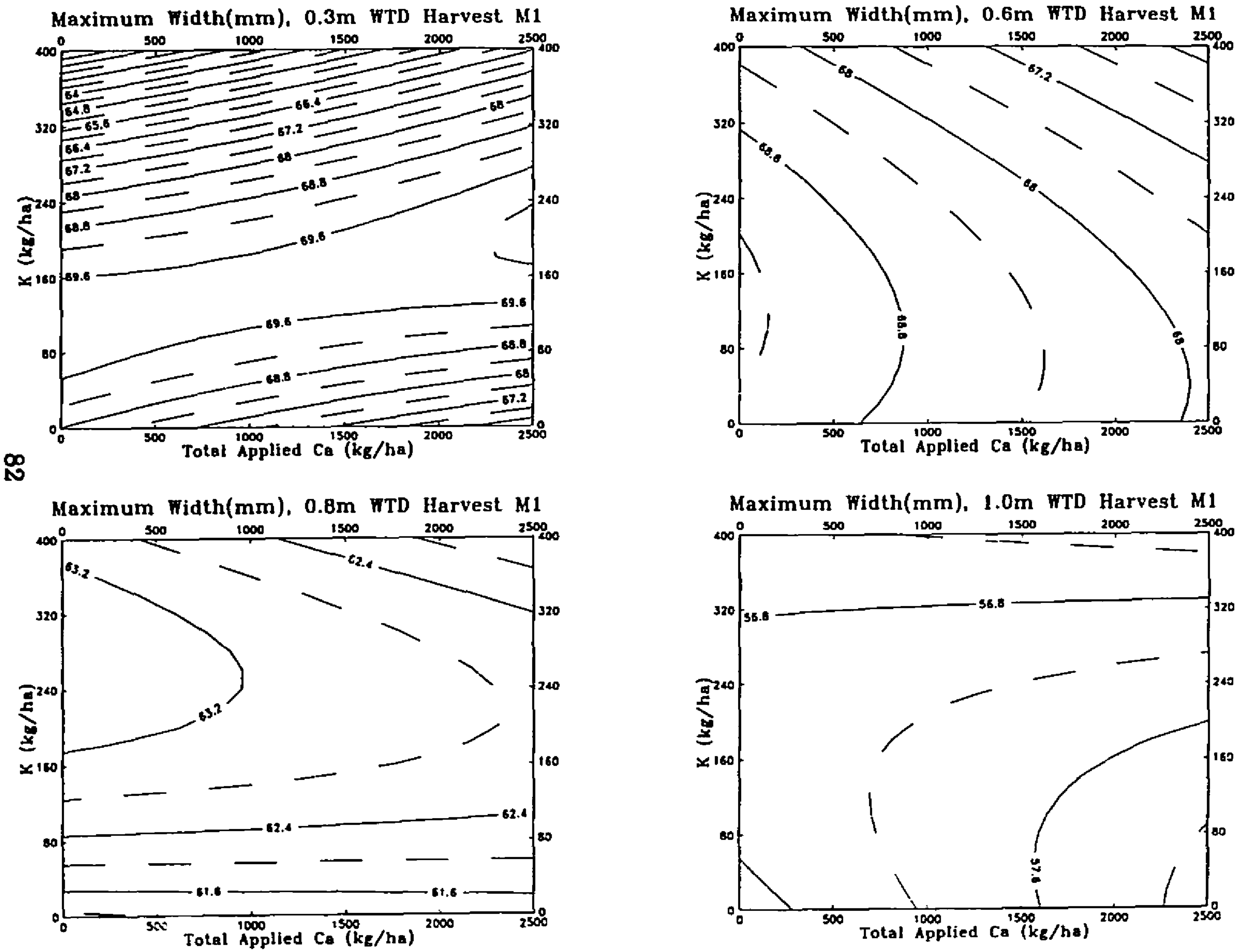

Maximum Width(mm), 0.3m WTD Harvest M1
Maximum Width(mm), 0.6m WTD Harvest M1
Maximum Width(mm), 0.8m WTD Harvest M1
Maximum Width(mm), 1.0m WTD Harvest M1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A10

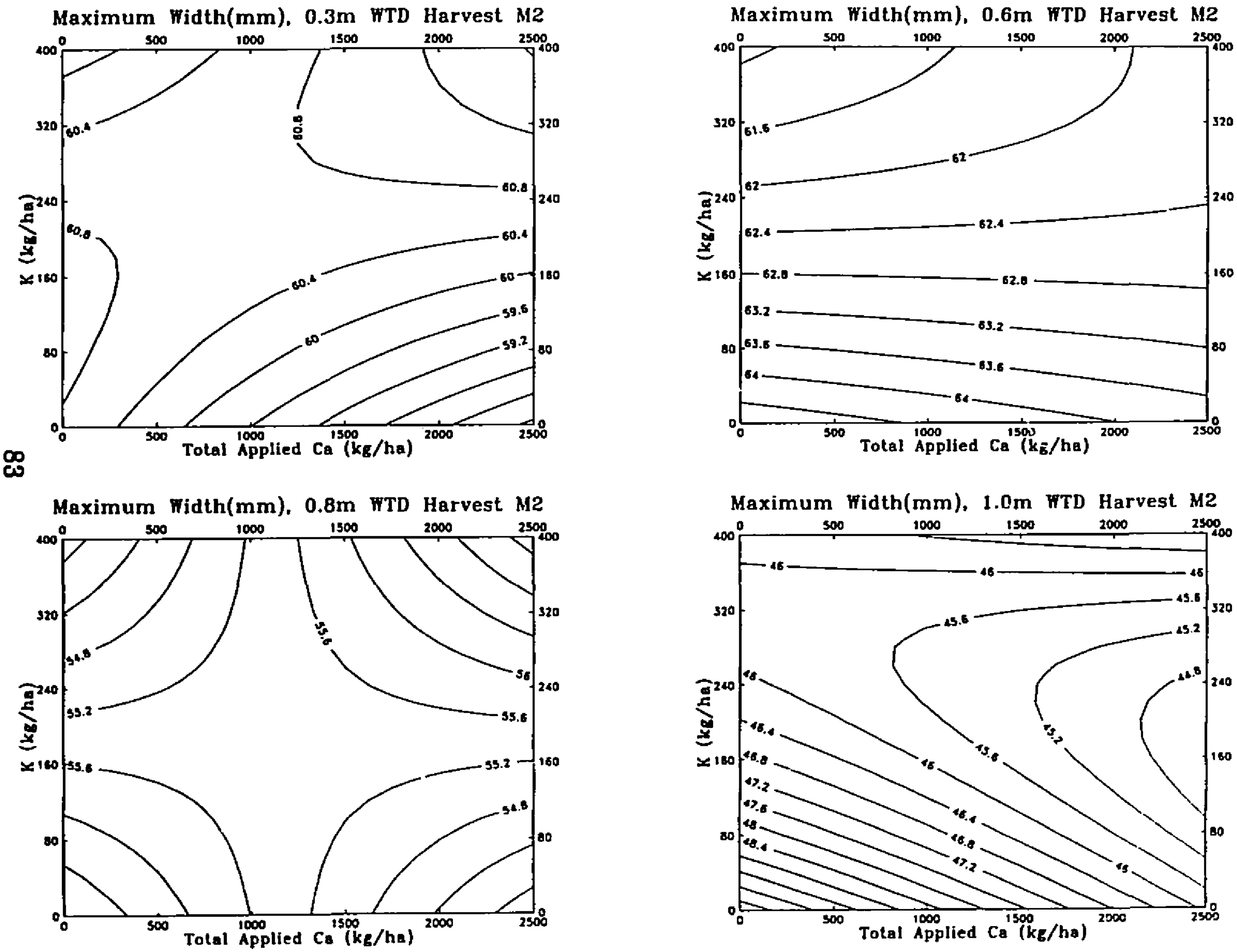
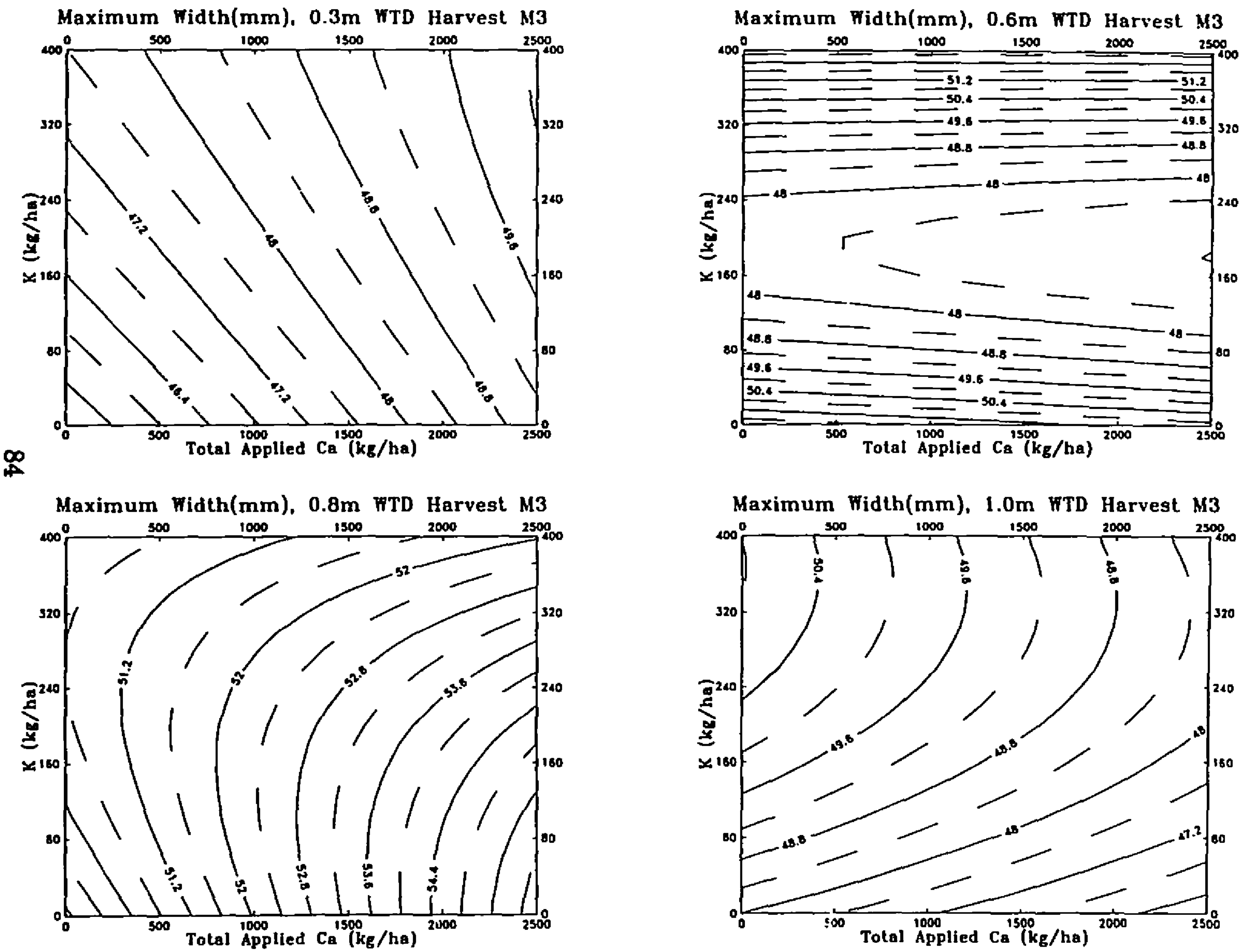
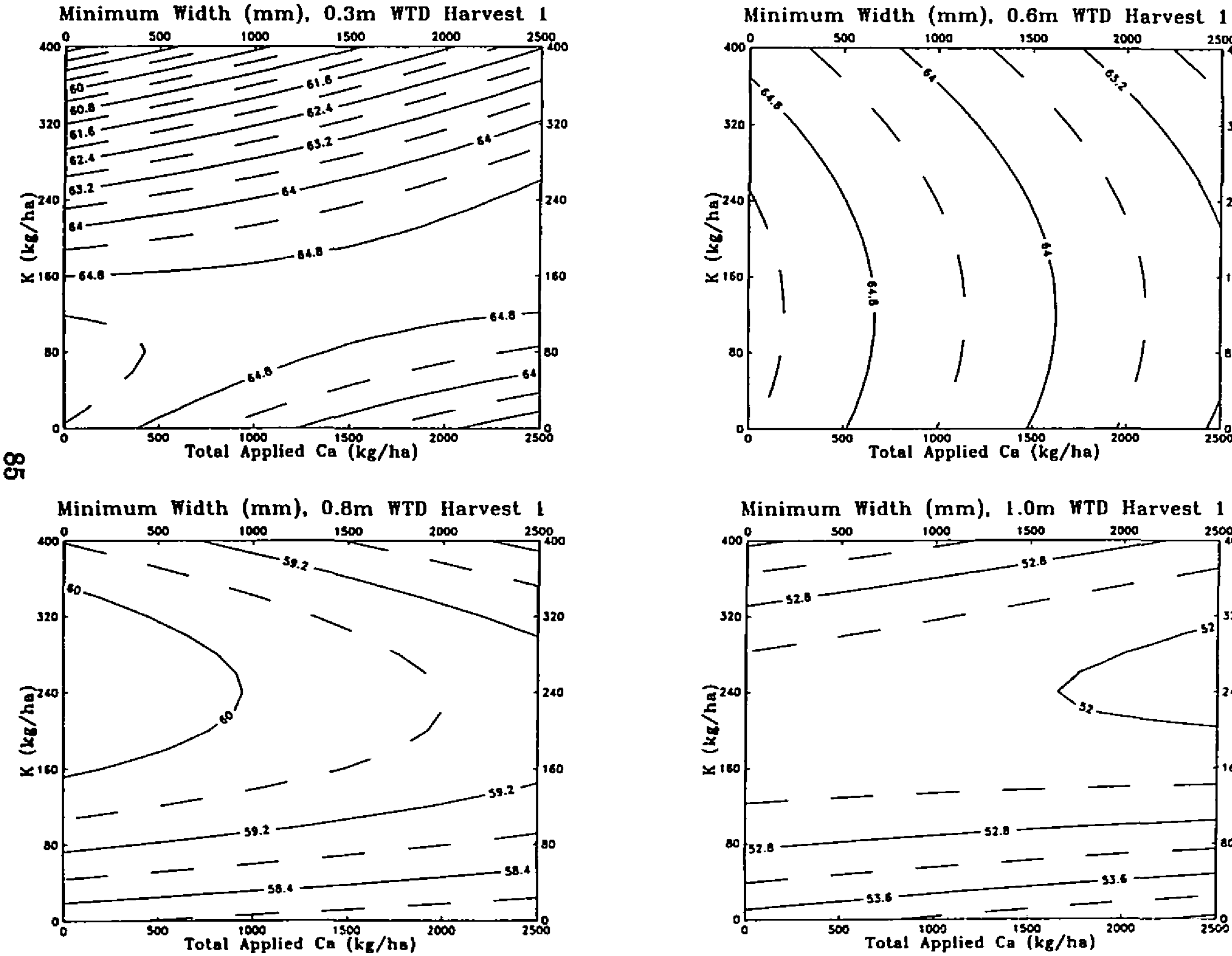

Maximum Width(mm), 0.3m WTD Harvest M2
Maximum Width(mm), 0.6m WTD Harvest M2
Maximum Width(mm), 0.8m WTD Harvest M2
Maximum Width(mm), 1.0m WTD Harvest M2
K (kg/ha)
Total Applied Ca (kg/ha)
0
500
1000
1500
2000
2500
80
160
240
320
400
60.4
60.8
60
59.6
59.2
61.6
62
62.4
62.8
63.2
63.6
64
54.8
55.2
55.6
56
46
45.6
45.2
44.8
46.4
46.8
47.2
47.6
48
48.4

Figure A11



Maximum Width(mm), 0.3m WTD Harvest M3
K (kg/ha)
Total Applied Ca (kg/ha)
Maximum Width(mm), 0.6m WTD Harvest M3
K (kg/ha)
Total Applied Ca (kg/ha)
Maximum Width(mm), 0.8m WTD Harvest M3
K (kg/ha)
Total Applied Ca (kg/ha)
Maximum Width(mm), 1.0m WTD Harvest M3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A12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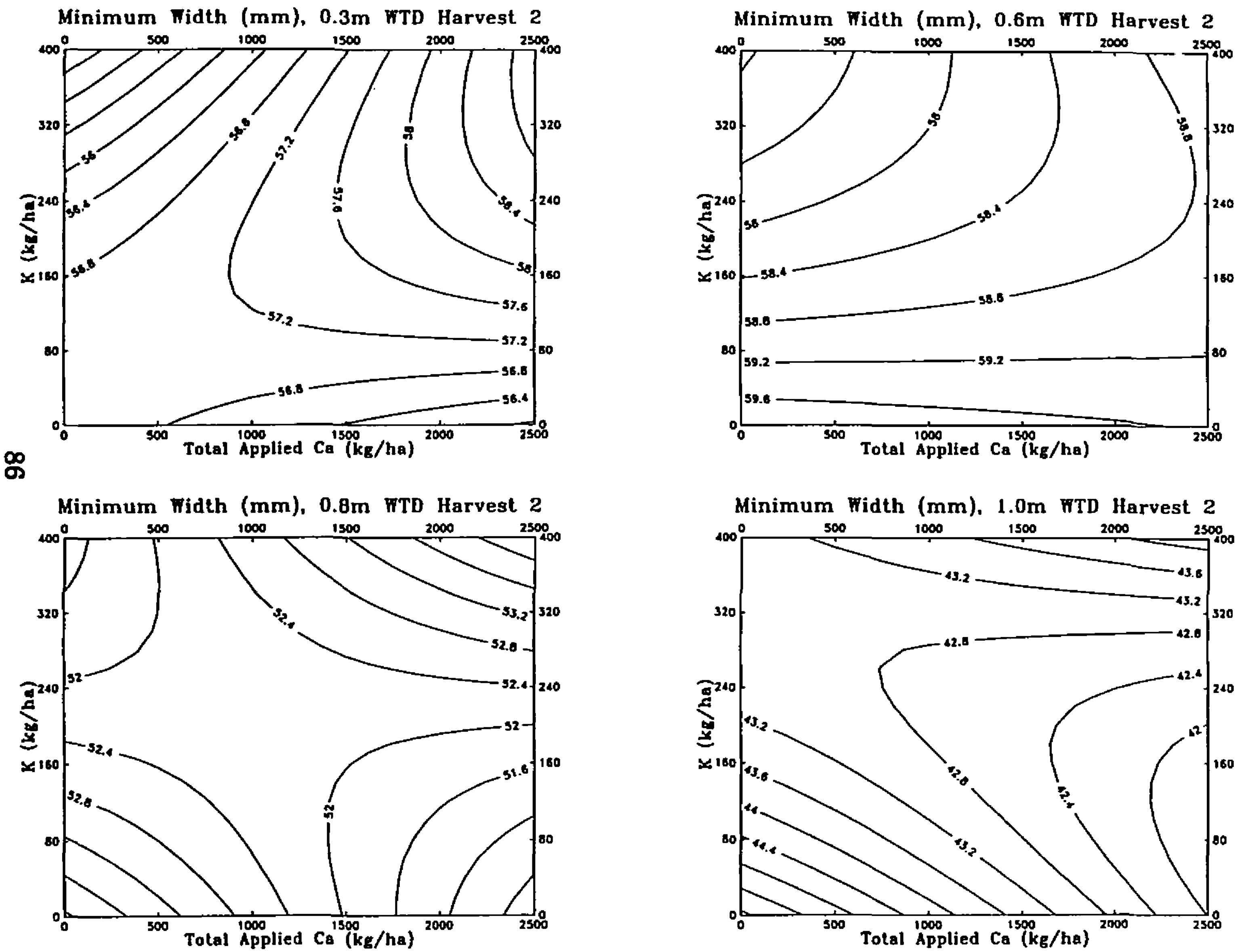
Minimum Width (mm), 0.6m WTD Harvest 1
Minimum Width (mm), 0.8m WTD Harvest 1
Minimum Width (mm), 1.0m WTD Harvest 1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A18



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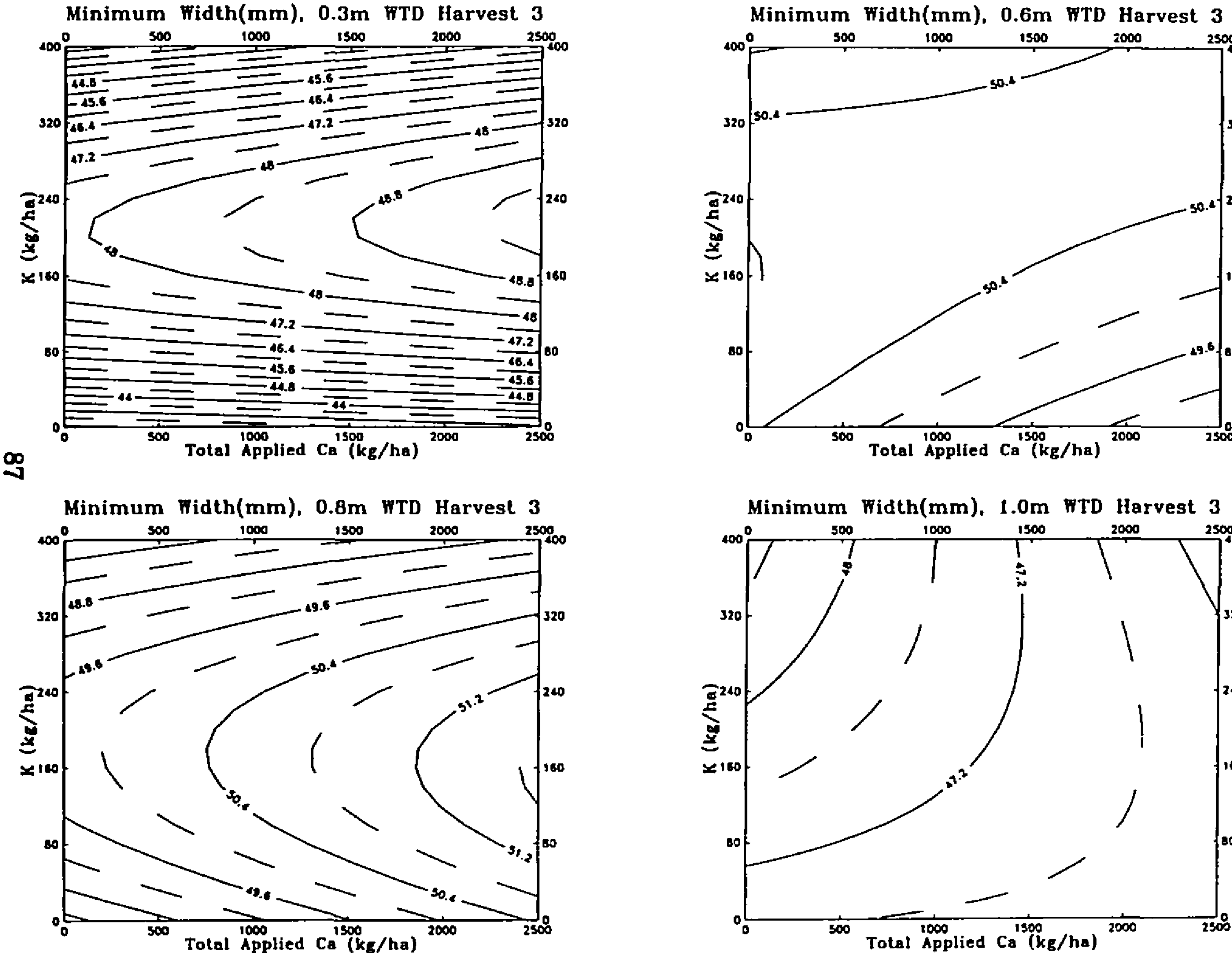
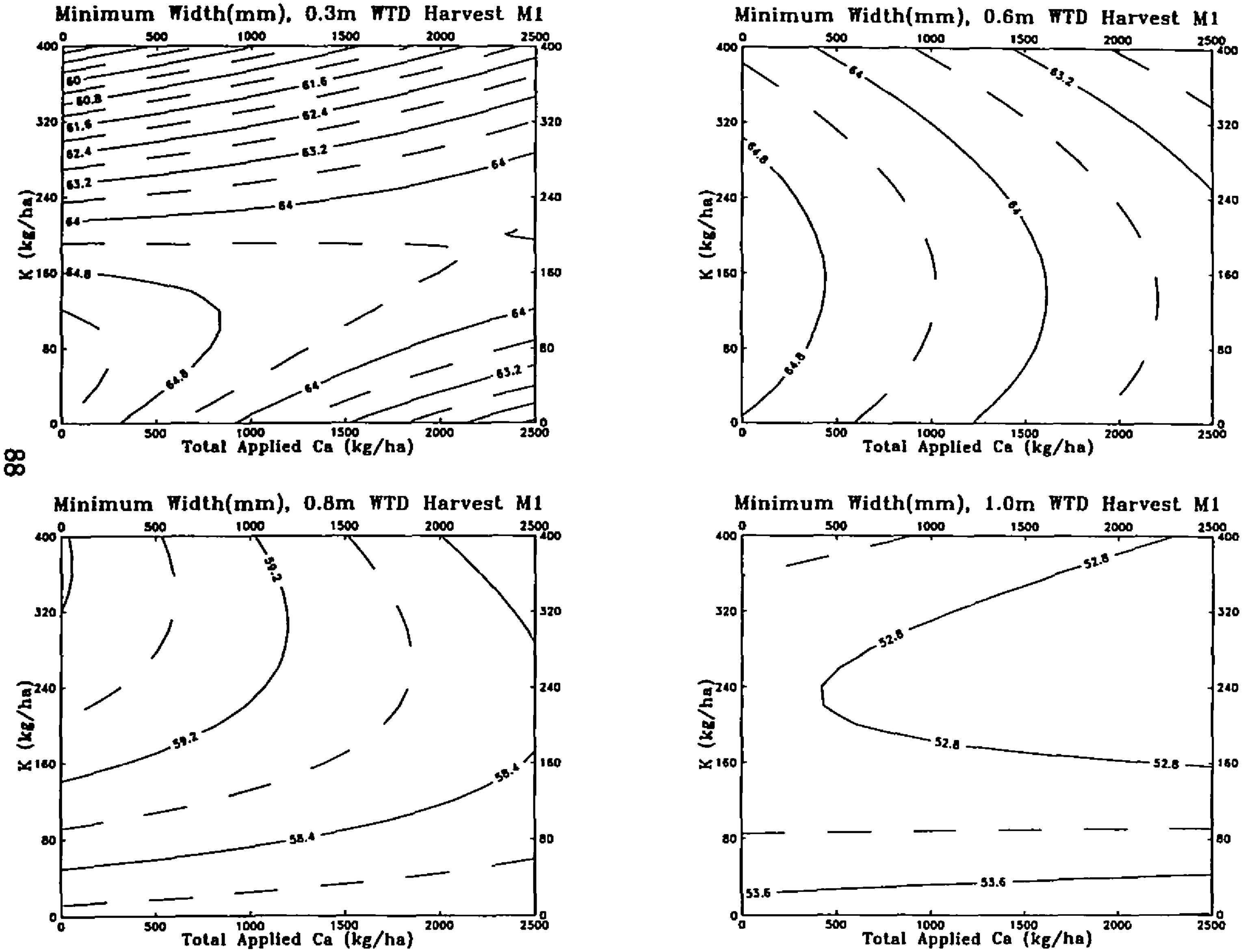
Minimum Width (mm), 0.6m WTD Harvest 2
Minimum Width (mm), 0.8m WTD Harvest 2
Minimum Width (mm), 1.0m WTD Harvest 2
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A14



Minimum Width(mm), 0.3m WTD Harvest 3
Minimum Width(mm), 0.6m WTD Harvest 3
Minimum Width(mm), 0.8m WTD Harvest 3
Minimum Width(mm), 1.0m WTD Harvest 3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A15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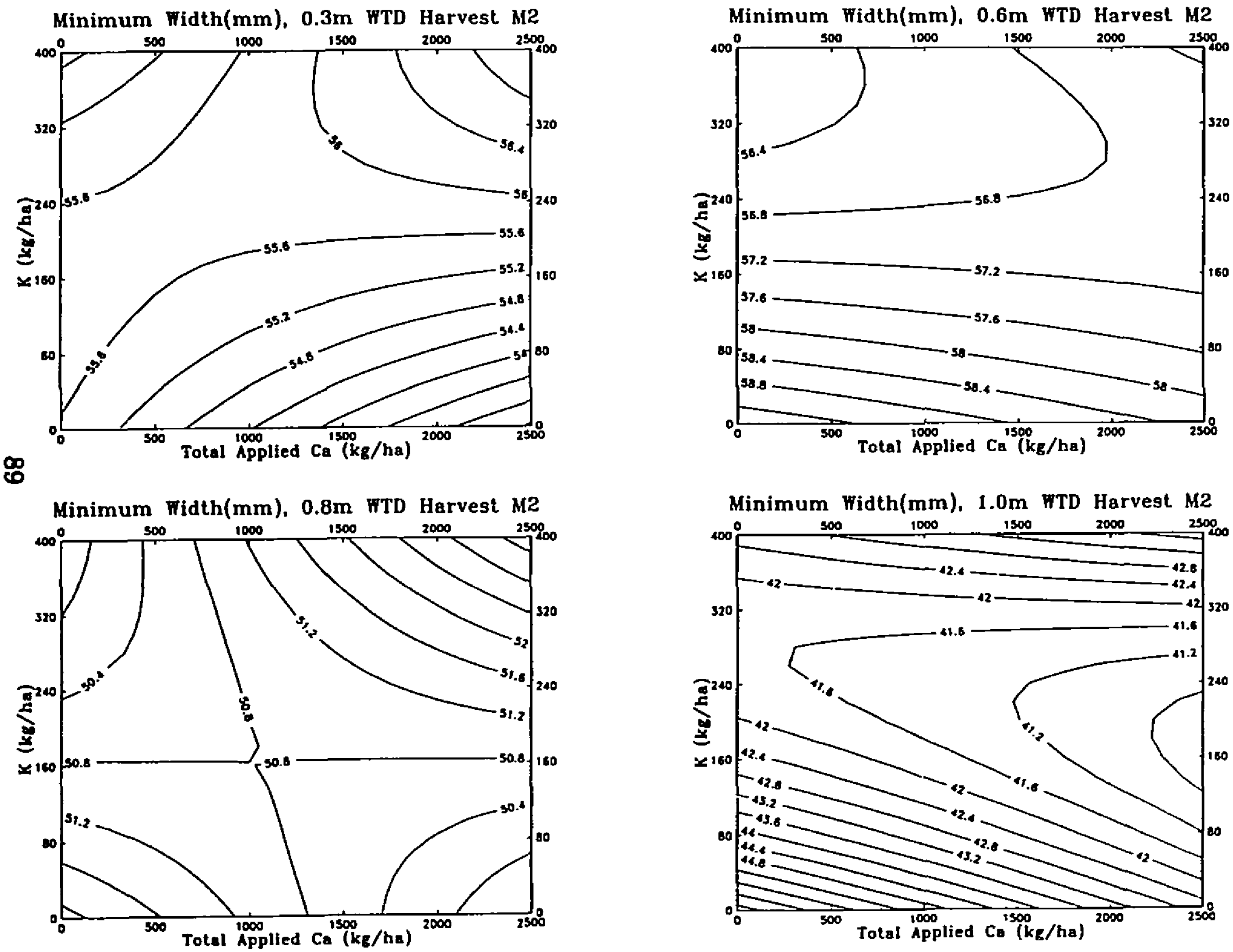
Minimum Width(mm), 0.6m WTD Harvest M1
Minimum Width(mm), 0.8m WTD Harvest M1
Minimum Width(mm), 1.0m WTD Harvest M1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A16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Minimum Width(mm), 0.6m WTD Harvest M2
Minimum Width(mm), 0.8m WTD Harvest M2
Minimum Width(mm), 1.0m WTD Harvest M2
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A17

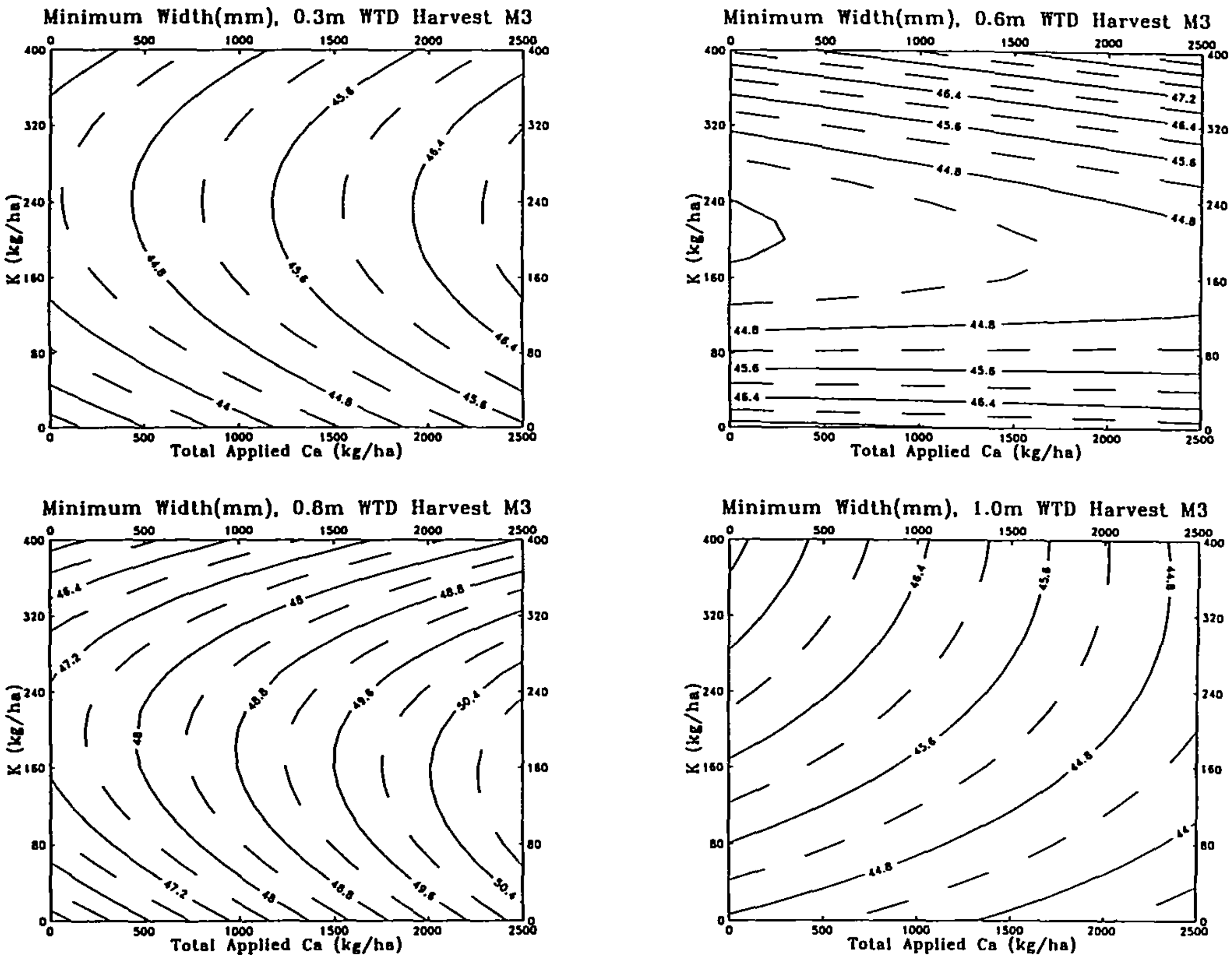
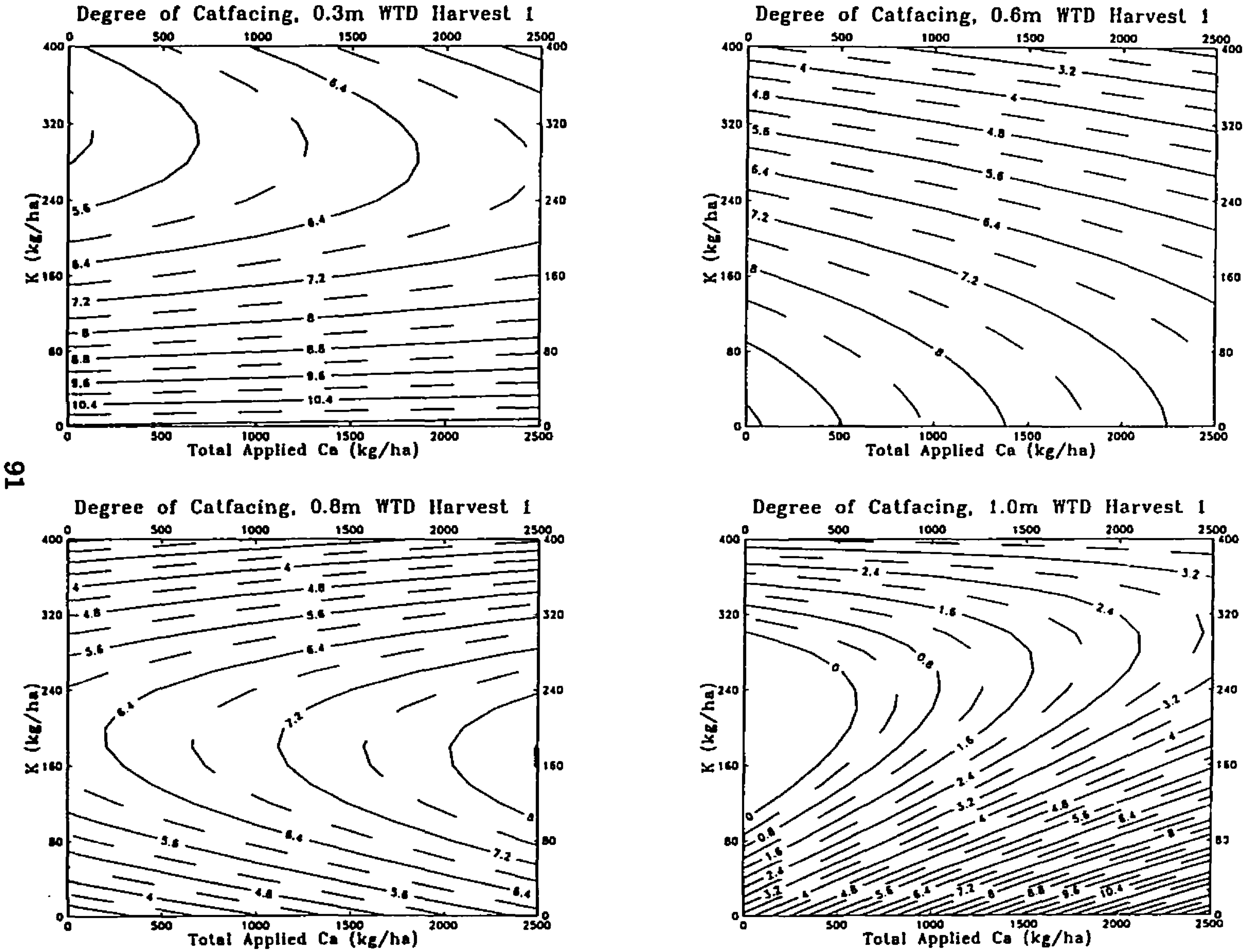

Minimum Width(mm), 0.3m WTD Harvest M3
Minimum Width(mm), 0.6m WTD Harvest M3
Minimum Width(mm), 0.8m WTD Harvest M3
Minimum Width(mm), 1.0m WTD Harvest M3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A18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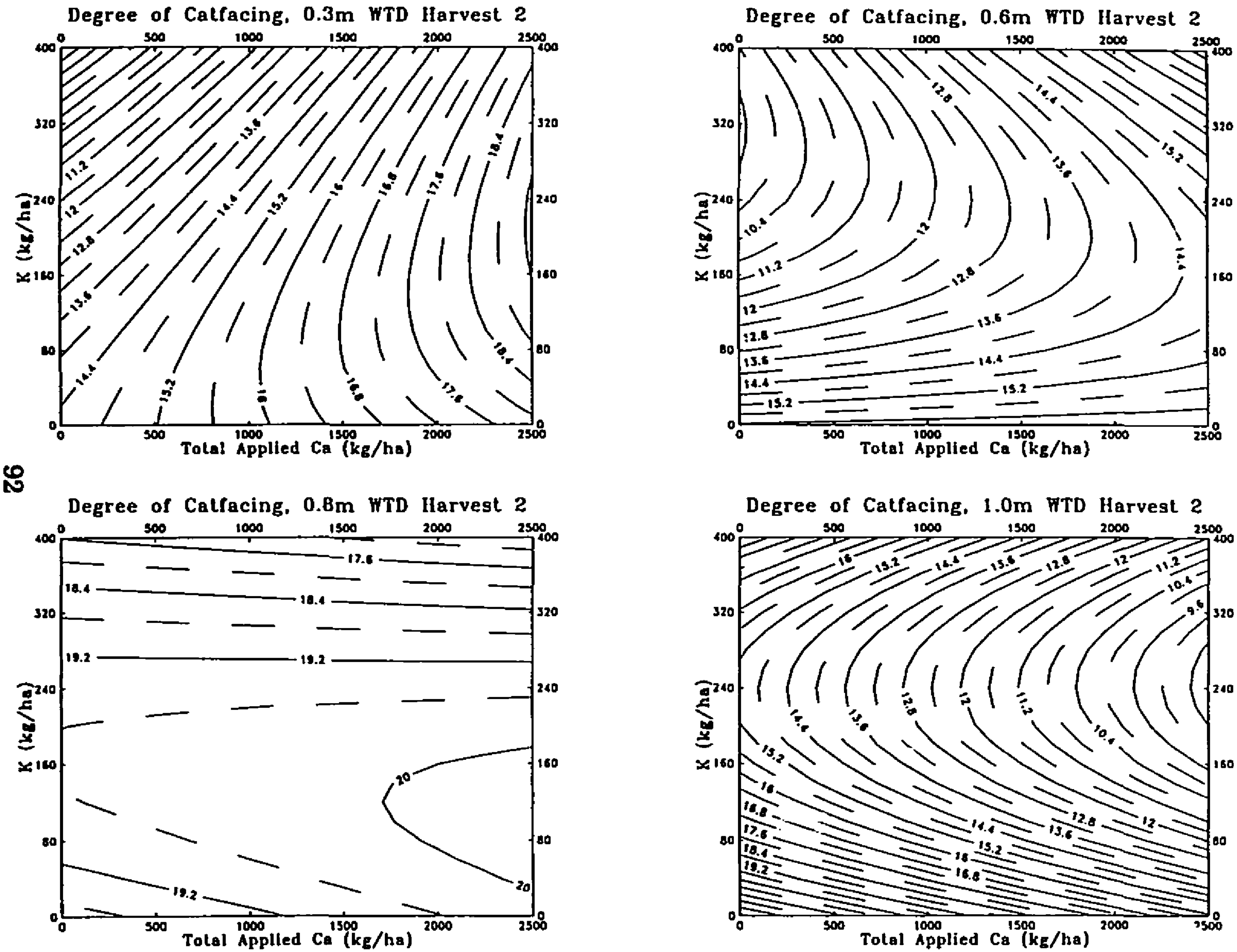
Degree of Catfacing, 0.6m WTD Harvest 1
Degree of Catfacing, 0.8m WTD Harvest 1
Degree of Catfacing, 1.0m WTD Harvest 1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A19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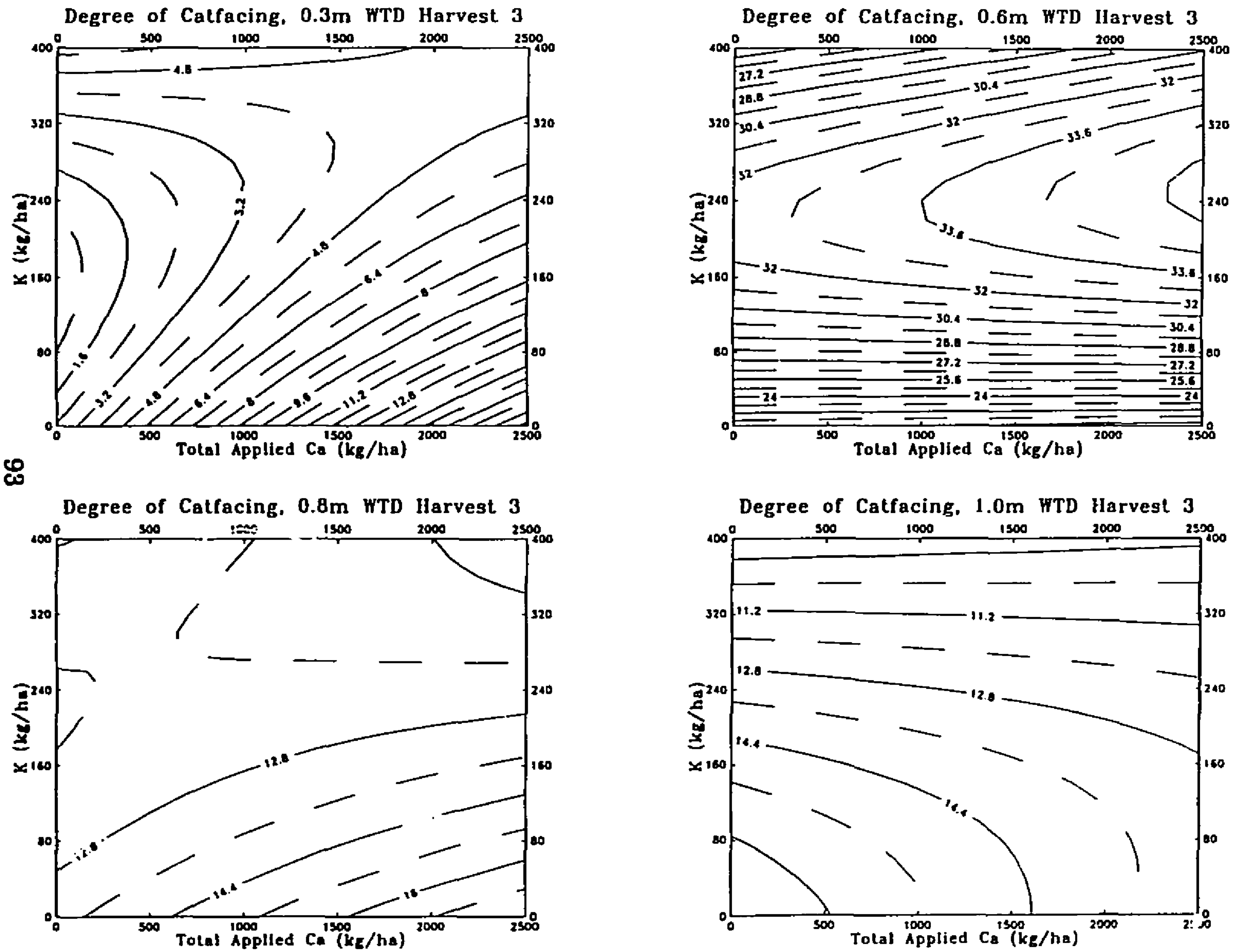
Degree of Catfacing, 0.6m WTD Harvest 2
Degree of Catfacing, 0.8m WTD Harvest 2
Degree of Catfacing, 1.0m WTD Harvest 2
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A20



Degree of Catfacing, 0.3m WTD Harvest 3
Degree of Catfacing, 0.6m WTD Harvest 3
Degree of Catfacing, 0.8m WTD Harvest 3
Degree of Catfacing, 1.0m WTD Harvest 3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A21

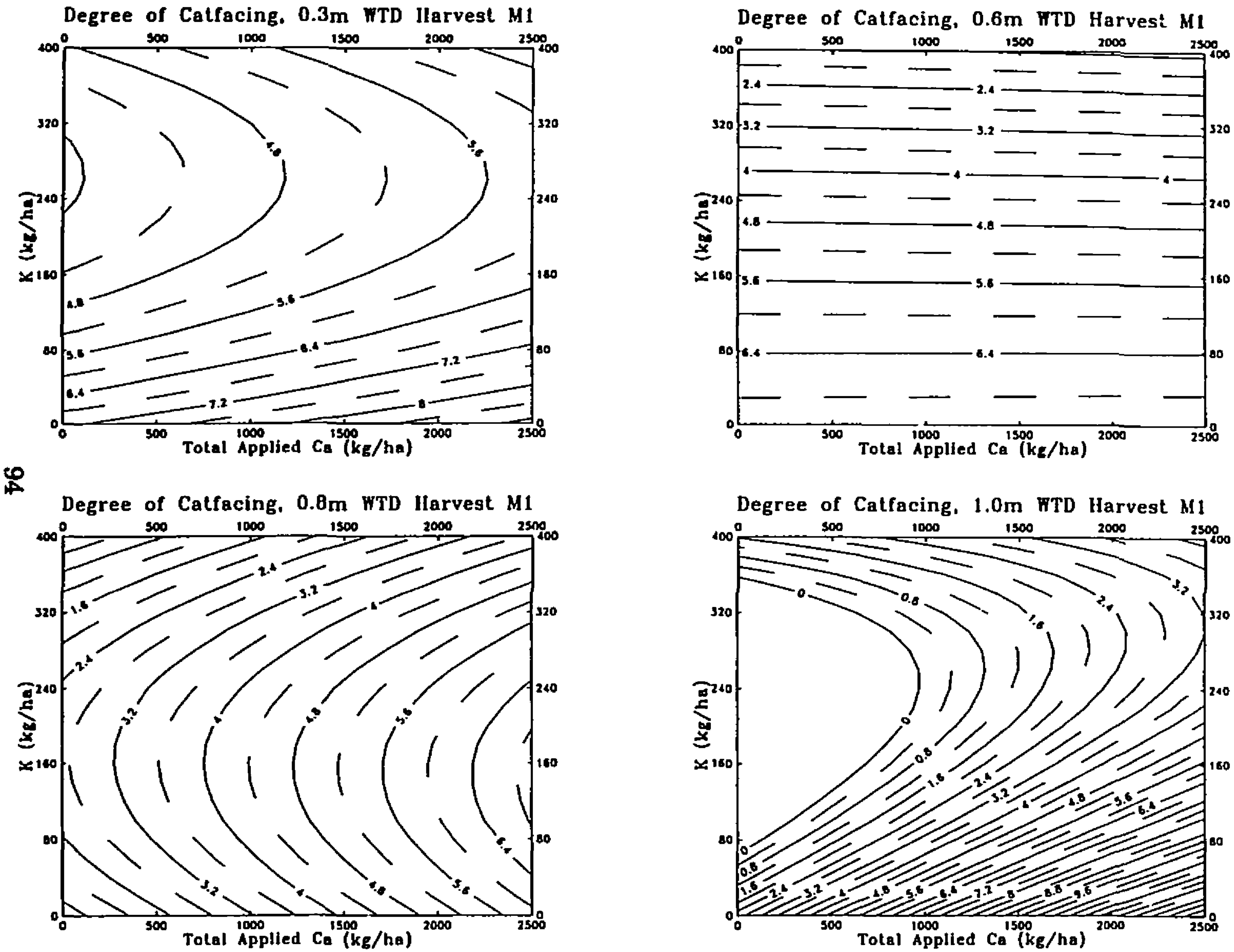

Degree of Catfacing, 0.3m WTD Harvest M1
Degree of Catfacing, 0.6m WTD Harvest M1
Degree of Catfacing, 0.8m WTD Harvest M1
Degree of Catfacing, 1.0m WTD Harvest M1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A22

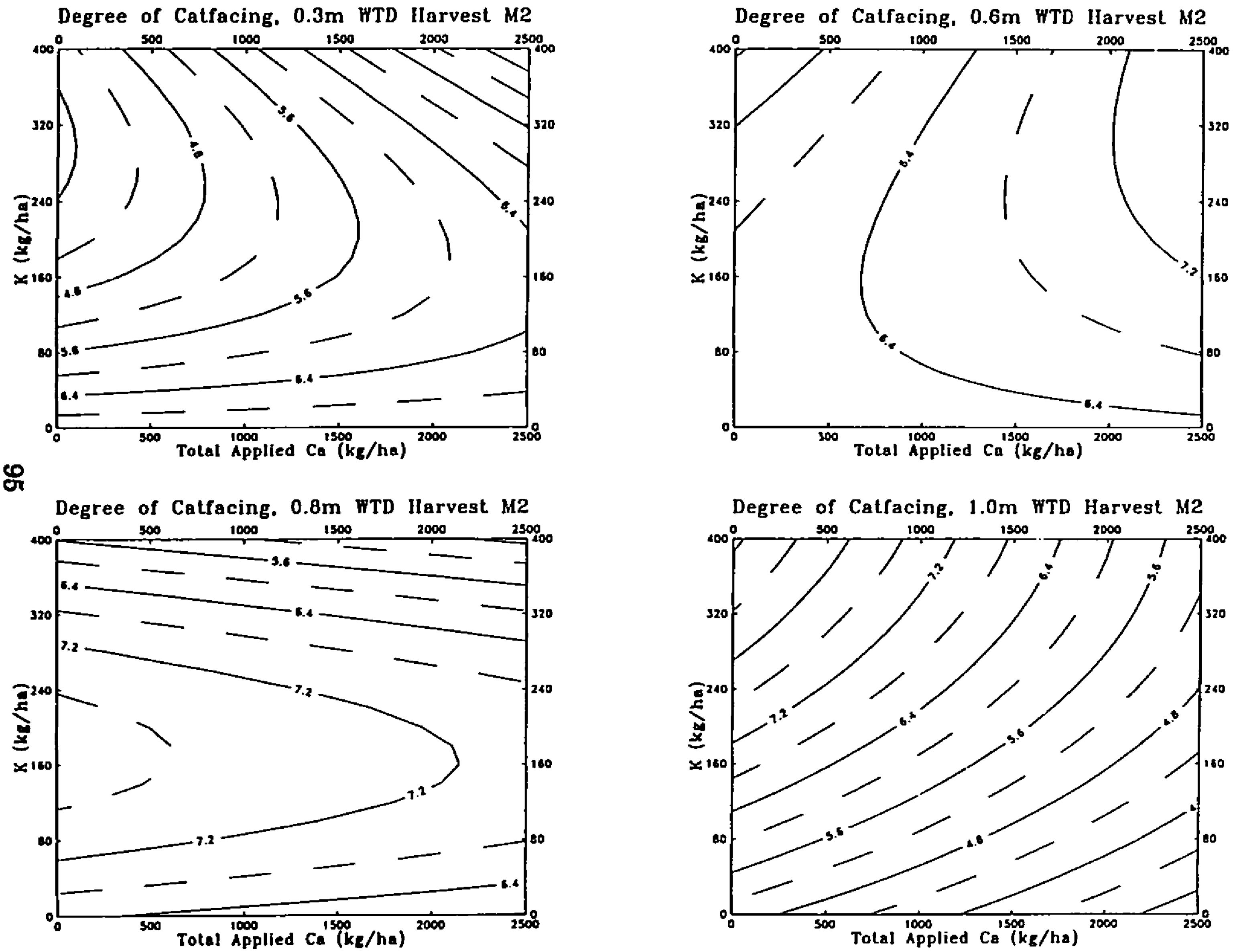
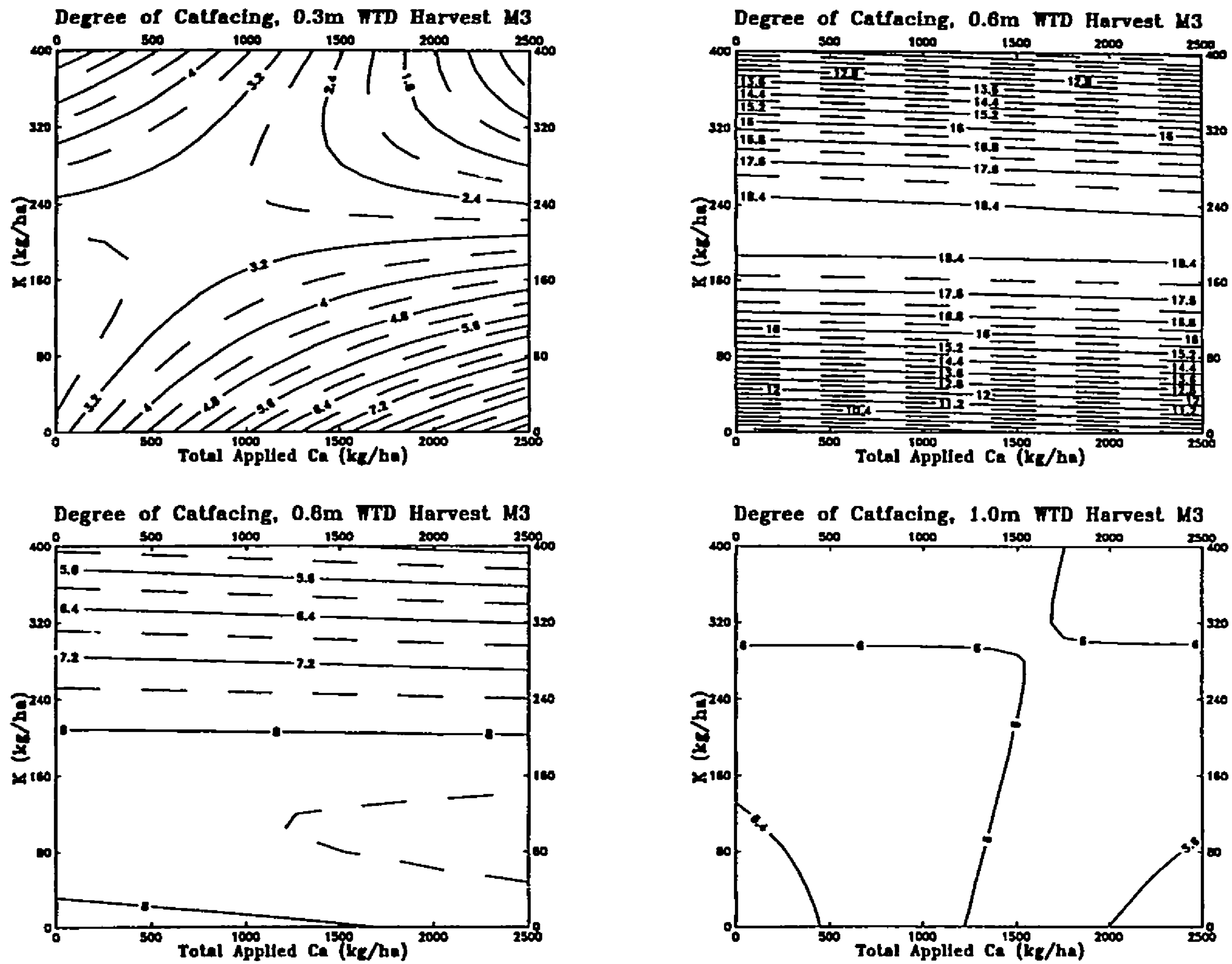
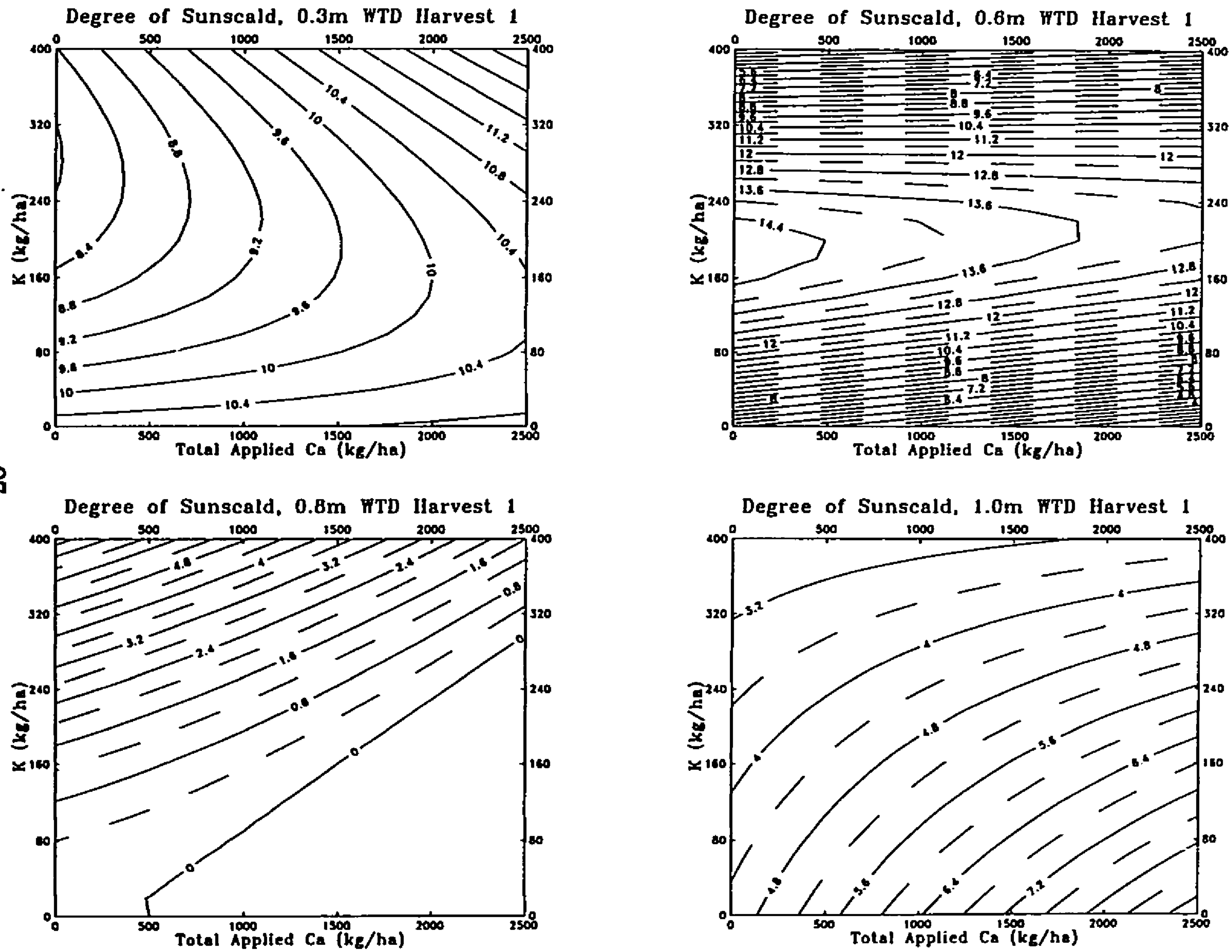

Degree of Catfacing, 0.3m WTD Harvest M2
Degree of Catfacing, 0.6m WTD Harvest M2
Degree of Catfacing, 0.8m WTD Harvest M2
Degree of Catfacing, 1.0m WTD Harvest M2
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A23



Degree of Catfacing, 0.3m WTD Harvest M3
Degree of Catfacing, 0.6m WTD Harvest M3
Degree of Catfacing, 0.8m WTD Harvest M3
Degree of Catfacing, 1.0m WTD Harvest M3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A24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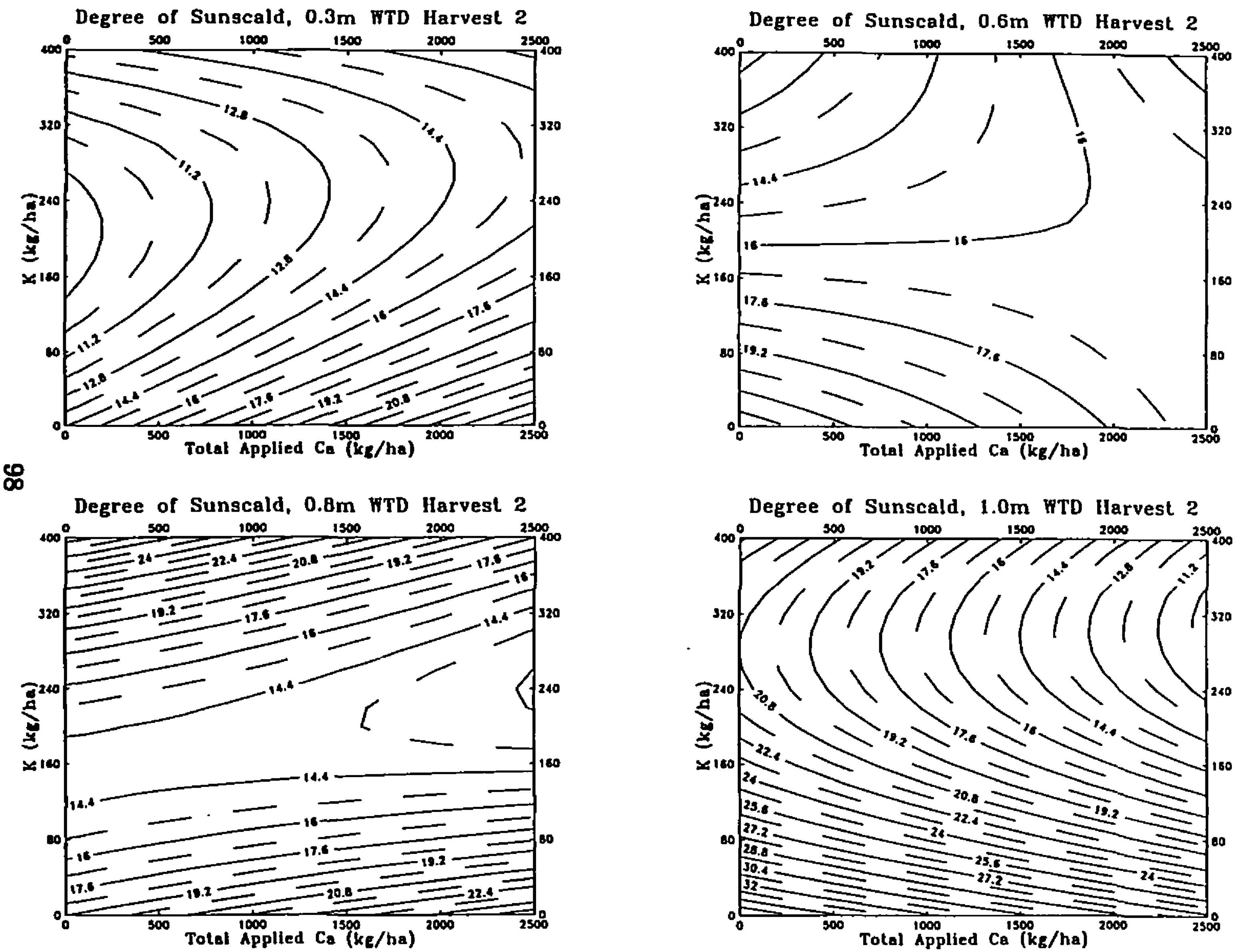
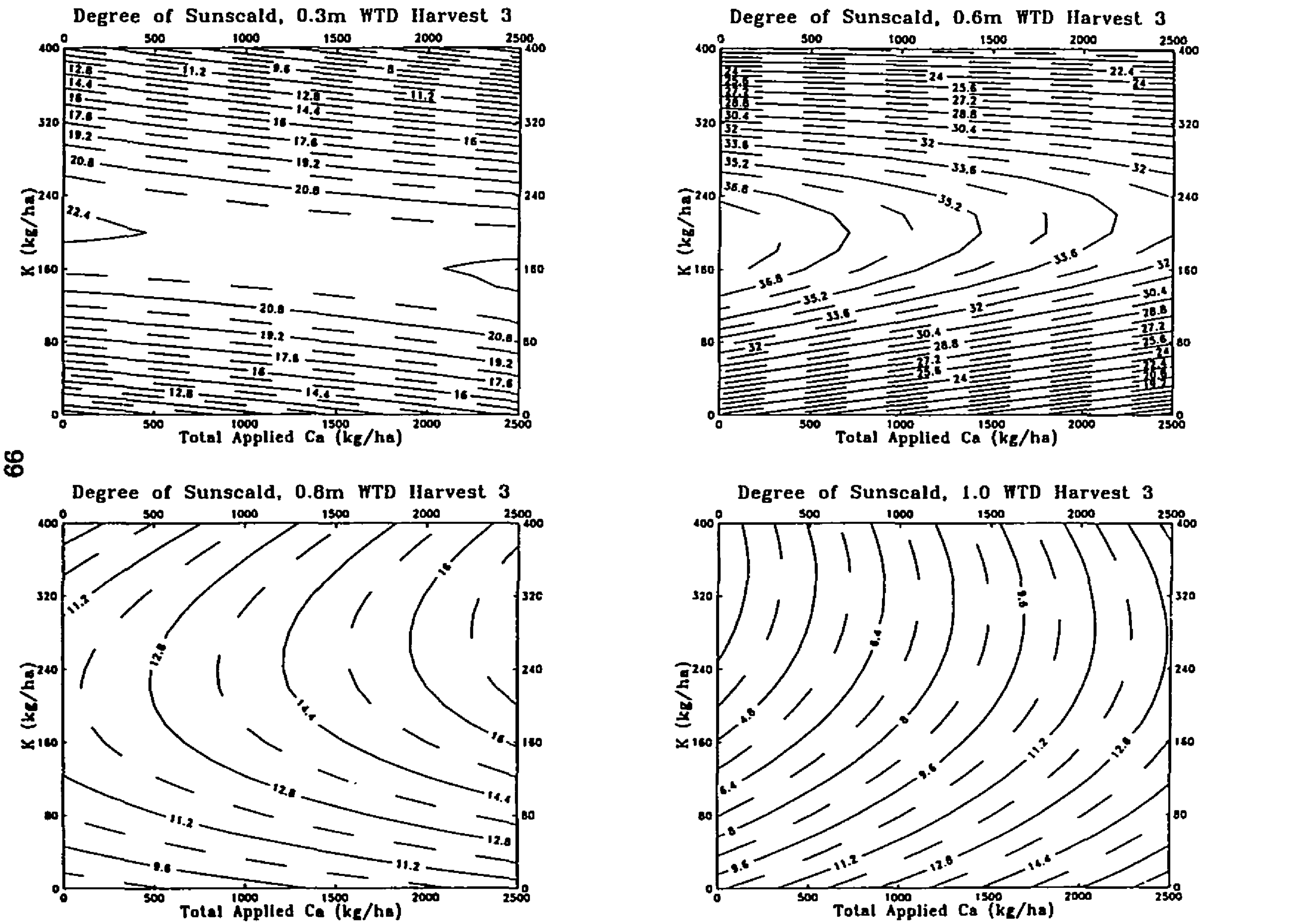
Degree of Sunscald, 0.6m WTD Harvest 1
Degree of Sunscald, 0.8m WTD Harvest 1
Degree of Sunscald, 1.0m WTD Harvest 1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A25



Degree of Sunscald, 0.3m WTD Harvest 2
Degree of Sunscald, 0.6m WTD Harvest 2
Degree of Sunscald, 0.8m WTD Harvest 2
Degree of Sunscald, 1.0m WTD Harvest 2
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A26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Degree of Sunscald, 0.6m WTD Harvest 3
Degree of Sunscald, 0.8m WTD Harvest 3
Degree of Sunscald, 1.0 WTD Harvest 3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A27

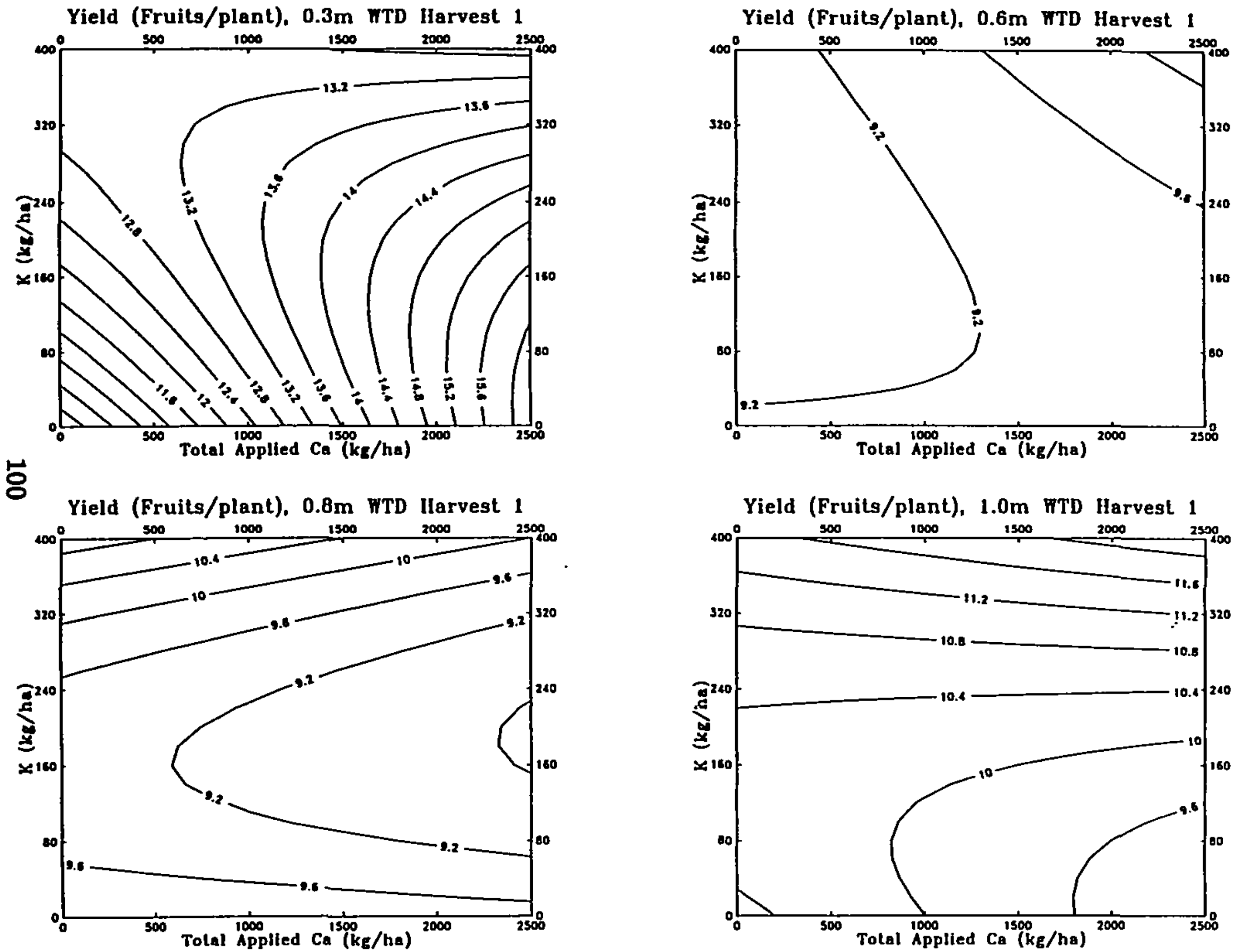
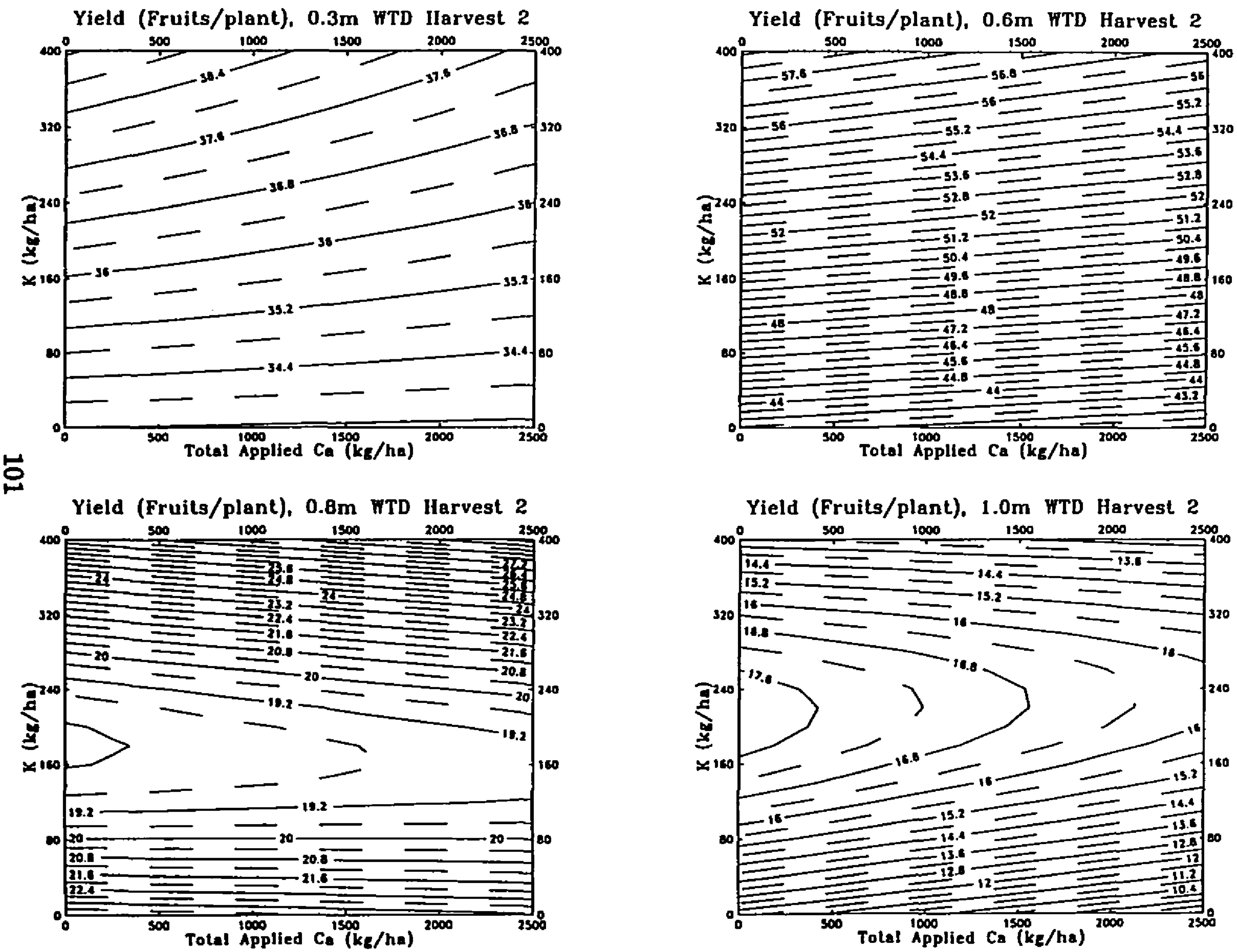

Yield (Fruits/plant), 0.3m WTD Harvest 1
Yield (Fruits/plant), 0.6m WTD Harvest 1
Yield (Fruits/plant), 0.8m WTD Harvest 1
Yield (Fruits/plant), 1.0m WTD Harvest 1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A28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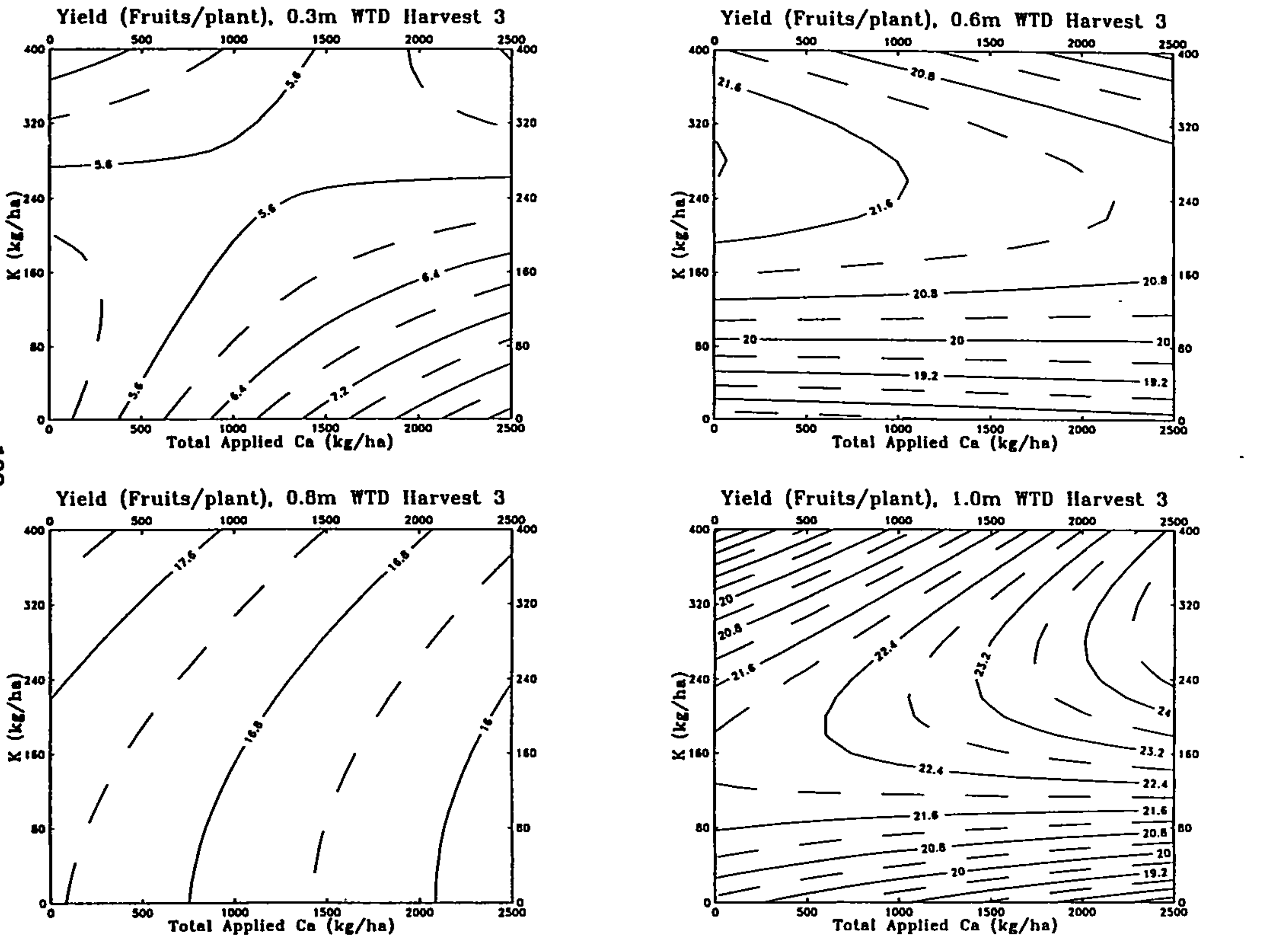
Yield (Fruits/plant), 0.6m WTD Harvest 2
Yield (Fruits/plant), 0.8m WTD Harvest 2
Yield (Fruits/plant), 1.0m WTD Harvest 2
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A29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Yield (Fruits/plant), 0.6m WTD Harvest 3
Yield (Fruits/plant), 0.8m WTD Harvest 3
Yield (Fruits/plant), 1.0m WTD Harvest 3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A30

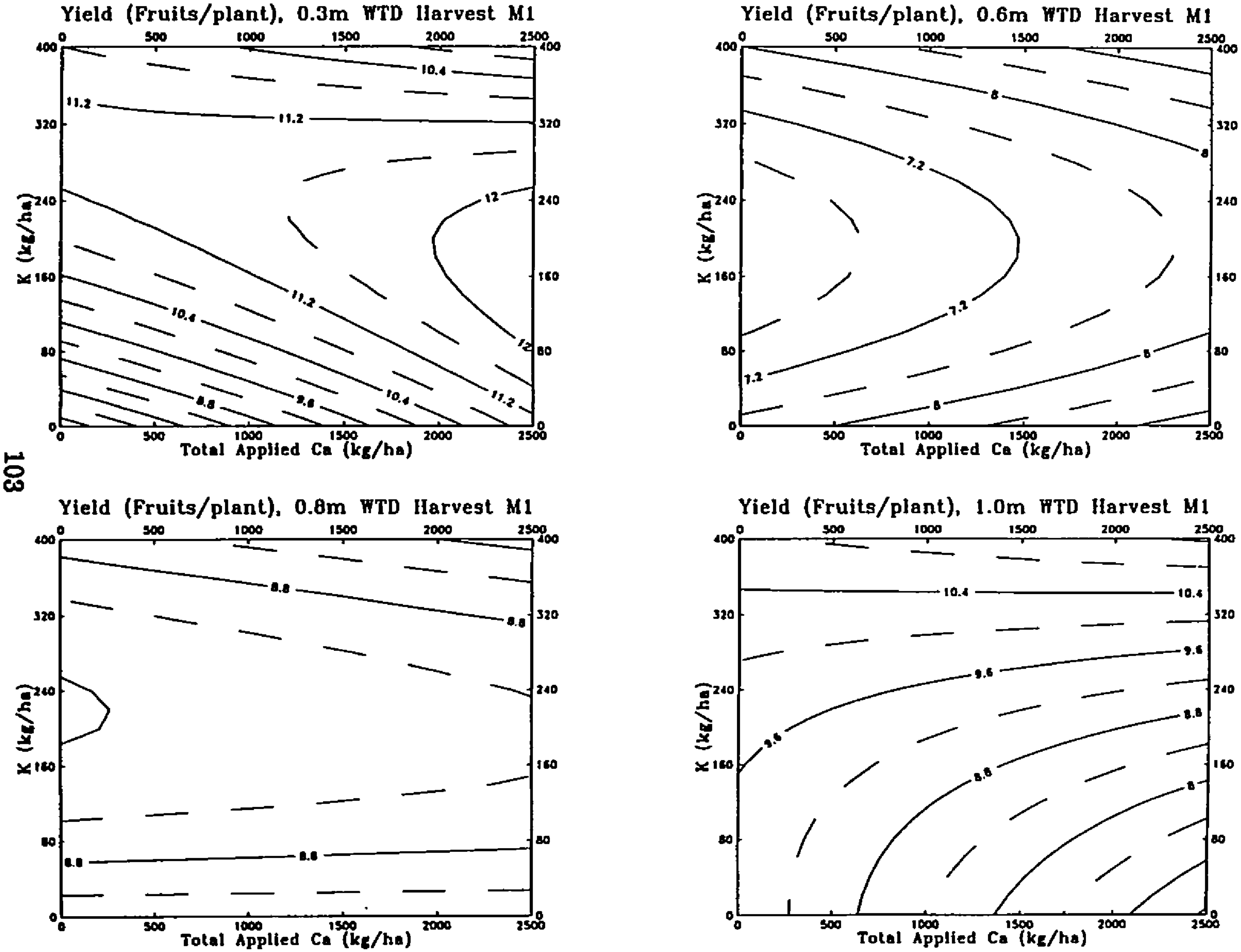
Yield (Fruits/plant), 0.3m WTD Harvest M1
Yield (Fruits/plant), 0.6m WTD Harvest M1
Yield (Fruits/plant), 0.8m WTD Harvest M1
Yield (Fruits/plant), 1.0m WTD Harvest M1
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A31

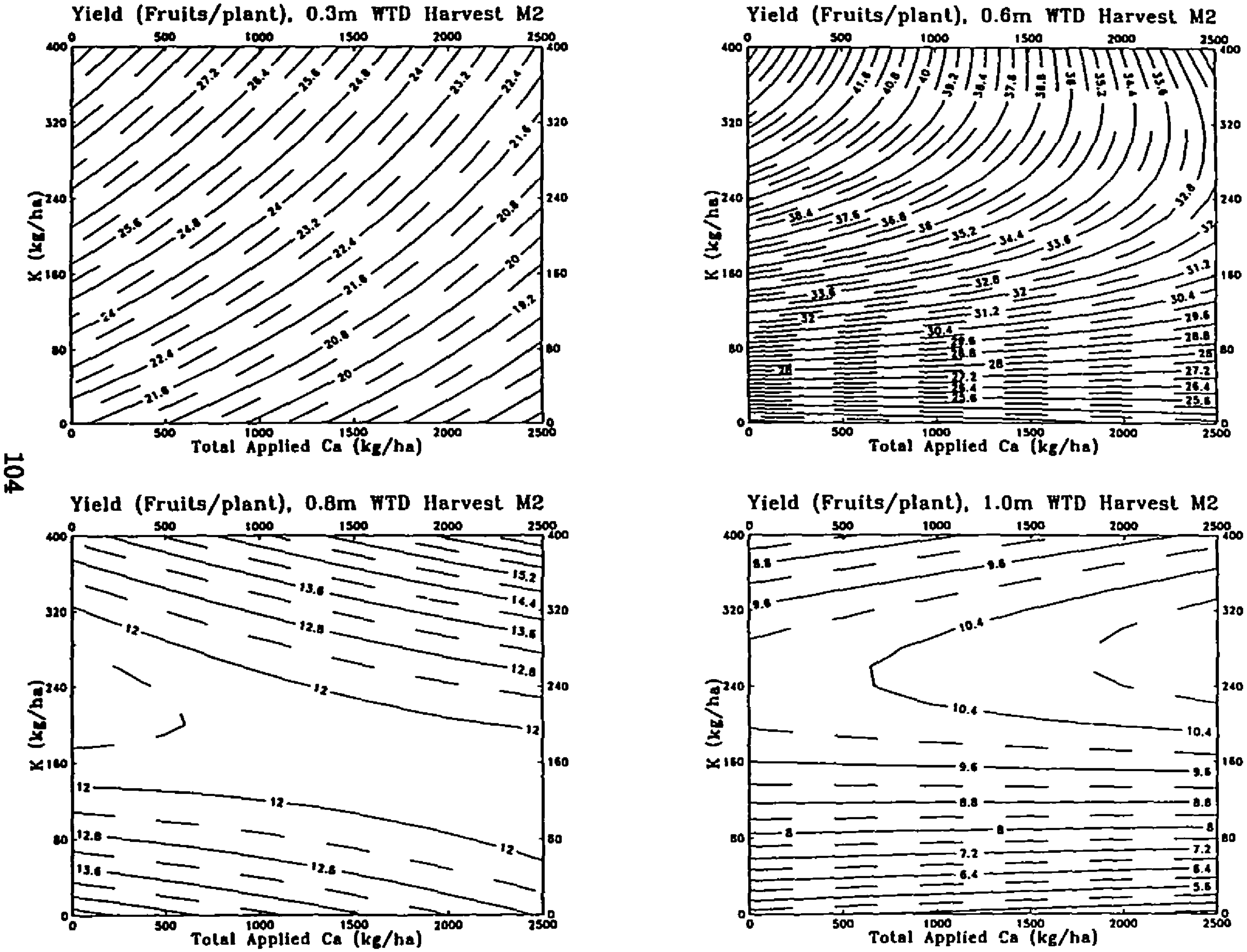
Yield (Fruits/plant), 0.3m WTD Harvest M2
Yield (Fruits/plant), 0.6m WTD Harvest M2
Yield (Fruits/plant), 0.8m WTD Harvest M2
Yield (Fruits/plant), 1.0m WTD Harvest M2
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A32

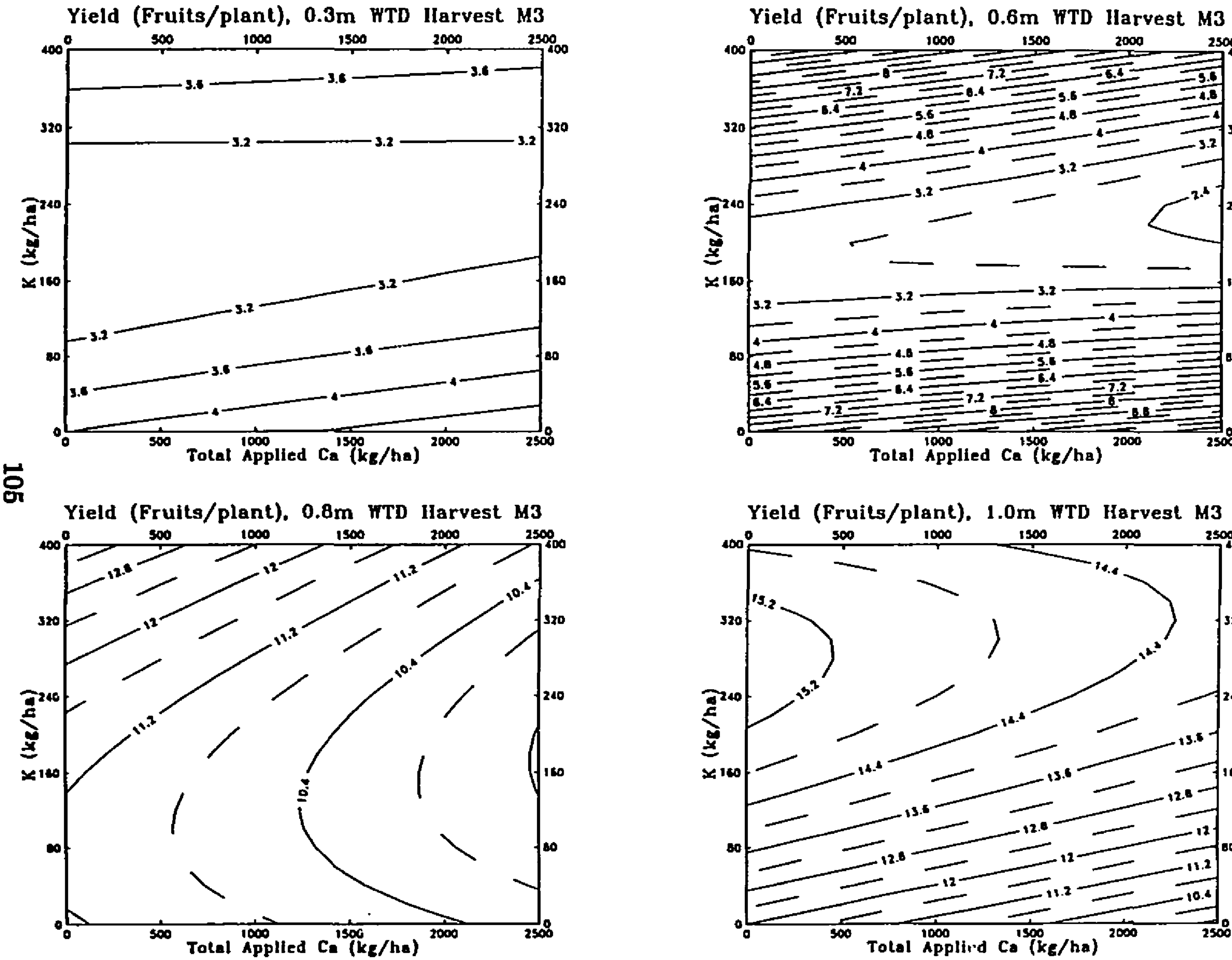
Yield (Fruits/plant), 0.3m WTD Harvest M3
Yield (Fruits/plant), 0.6m WTD Harvest M3
Yield (Fruits/plant), 0.8m WTD Harvest M3
Yield (Fruits/plant), 1.0m WTD Harvest M3
K (kg/ha)
Total Applied Ca (kg/ha)

Figure A33

Appendix B

SAS program for Statistical analysis

APPENDIX B

Basic SAS program for statistical analysis by water table depth.

```
DATA A;
INFILE'u:\private\trenholm\stat\ugysepar.prn 'lrecl=200;
INPUT harvest WTD lysm K CA height maxwid minwid catfac sunsc yield;
IF WTD NE 25 OR HARVEST NE 1 THEN DELETE;
PROC SORT;
BY WTD K CA;
PROC MEANS;
BY WTD K CA;
PROC PRINT;
PROC GLM;
MODEL height maxwid minwid catfac sunsc yield = CA K K*K CA*K/SS1;
BY WTD;
RUN;
```

Basic SAS program for overall statistical analysis.

```
DATA A;
INFILE'u:\private\trenholm\stat\ugysepar.prn 'lrecl=200;
INPUT harvest WTD lysm K CA height maxwid minwid catfac sunsc yield;
PROC PRINT;
PROC GLM;
MODEL height maxwid minwid catfac sunsc yield = CA K K*K CA*K/SS1;
BY WTD;
RUN;
```