FACTORS AFFECTING PLANT DENSITY AND COTTON YIELDS IN TURKMENISTAN

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Abstract

Cotton has been grown in central Asia for over 2,000 years, and is a major crop in Turkmenistan, where medium staple G. hirsutum is the dominant species, cultivated on 80% of the cotton growing area. Many of the cultivars used in Turkmenistan until the time of independence from Russia were from Uzbekistan. Since independence, the original suite of long staple G. barbadense and medium staple Uzbek cultivars has been considerably changed in Turkmenistan by selection for early maturity and productivity.

Cotton yields in Turkmenistan have been declining since independence and were below 2 t/ha in 2001 when the TACIS ‘Support to the Cotton Sector Project’\(^1\) commenced, of which research reported in this thesis was a part. The main factors determining seed cotton yields in this country are quantity of irrigation water applied, nitrogen fertilization, deep ploughing, and plant population. Of these four important factors, plant density is the only one that individual farmers can control, as the others are either state controlled or require equipment held collectively. Reports from agronomists working on the TACIS project in April 2001 suggested that plant populations on farms were low by international standards, and this was supported by measurements of population on two Government cotton research stations. However, the optimum population for modern Turkmen cultivars was unknown, so the significance of these reports could not be judged. The aim of the research described in this thesis was to improve cotton production in Turkmenistan through optimising plant population.

\(^1\) The European Union-funded ‘Support to the Cotton Sector Project’, which had the broad aim of improving cotton production in Turkmenistan.
To first test reports of low populations, plant densities were measured on 20 cotton fields throughout the main cotton growing area of Ahal Velayat, Turkmenistan in August-September 2001. Populations were in the range 20,000–59,000 plants/ha with a mean of 45,000 plants/ha. There was a weak positive correlation between plant population and yield.

Amongst the five lowest yielding fields in the survey (mean yield 1.18 t/ha seed cotton) there was a high negative correlation between plant population and boll numbers per plant ($r = -1.0, P<0.05$) and boll weights ($r = -0.9, P<0.05$); suggesting that in these low yielding fields, plants were competing for resources such as nutrients and water that were the primary constraint on yield, rather than low population. There was a decline in yield per hectare with increasing population ($r = -0.59, P<0.05$) in these low-yielding fields. Amongst the five highest yielding fields (mean yield 3.24 t/ha seed cotton), the correlation between plant population and boll numbers per plant ($r = -0.60, P<0.05$) and boll weight ($r = -0.48, P<0.05$) were only weakly negative, compared with the lower-yielding fields. In the higher-yielding fields there was a very small and statistically non-significant yield response to population ($r = -0.07, P>0.05$). These results indicated that in well-managed fields, plant populations could be further increased without large reductions in two important components of seed cotton yield.

Three experiments examined crop responses to population, and in one of these experiments irrigation frequency was also varied to see if lower populations were needed when good irrigation supply could not be assured (a possible factor explaining low yields in some of the surveyed fields). In these experiments, the optimum population for the modern Turkmen cultivars used was found to be around 100,000 plants/ha. Seed cotton yield increases from treatment populations of 50-55,000 plants/ha (at the highest end of those recorded in the field survey) to the optimum populations, ranged from 18%-77%. These yield increases were achieved with little reduction in fibre quality and none in economic grade of fibre. The
high yield increases in response to population appeared to be partly due to low ‘control’ population in the experiments (these simulated low surveyed field populations) and partly due to the morphology of the cotton cultivars used growing in the near insect free, short-season Turkmenistan environment. The use of optimum plant populations in the cotton fields of Turkmenistan has a substantial potential for economic benefit to the farmers of that country. Changing plant populations would require none of the structural changes involved in changing the other important yield factors. Quantity of irrigation water applied is controlled by the state; nitrogen fertilizer is a state controlled input in Turkmenistan and deep ploughing depends on equipment communally held and sometimes unavailable. However, any farmer can change plant population with a hoe.

A series of experiments was designed to find out why field plant populations are so low. Deep ploughing, draining and careful leveling of experimental areas was carried out in order to eliminate bulk density, drainage and salting as causal factors, so that the effect of soil borne diseases and early insect damage in reducing populations could be examined. Differences in treatment means were large in this experiment (between treatments that included the insecticide imidacloprid and those that did not) but not statistically significant. There was a significant difference in insect attack (bean aphid, *Smynthurodes betae* Kühn) when visually assessed, but no statistical differences in fibre quality, yield or maturity of the harvested treatments. Combined with reports of early season insect damage to crops in Surkhandarya, Uzbekistan in 2000, this indicates that early insect attack may be a factor limiting plant populations under certain conditions. The experiment found that soil borne fungal diseases do not significantly affect yield, quality or maturity of cotton in the environment of Turkmenistan.
In Turkmenistan, seed is planted at very high rates (over 300,000 plants/ha) and stands are thinned by hand not long after emergence. Poor thinning practice may explain the low population and gaps in rows observed in the field survey (the population experiments showed that low population per se rather than gaps were responsible for low yields at low populations). The effect of kind of hoe used for thinning and the ‘target’ plant population was experimentally determined using both Turkmen and Russian-style hoes. Hand thinning was found responsible for the low and variable plant density in farmer’s fields, as most of the operators evaluated lacked the dexterity to thin accurately to 10 plants/m².

A significant effect of row spacing on yield of cotton fibre was observed in an experiment examining row spaces x long staple cultivars x population (1,806 kg/ha seed cotton and 556 kg/ha fibre for 60 cm rows compared to 1,444 kg seed cotton/ha and 474 kg/ha fibre for 90 cm rows). Should it not be practical to change the current Turkmen system of machine planting and hand thinning, changing row spacing may bring about the required changes in plant populations from sub-optimum to optimum. The same experiment demonstrated a significant response in crop phenology to plant density, unrelated to treatment differences in either yield or maturity. COTMAN² curves developed for row spacing treatments in this experiment were the same, however. This led to the tentative hypothesis that light interception in canopies at the two row spaces used in this experiment were the same; and yield differences in them were due to different inter-plant spaces in the different row treatments rather than a row effect per se.

The results of these experiments were used to develop COTMAN curves for two medium staple and three long staple Turkmen cotton cultivars and also to use these curves to summarize plant phenology and characterize or explain treatment differences. These

² The crop-monitoring program COTMAN is based on the concept of NAWF (‘nodes above the white or fertilised flower’) as an indicator of cut-out and physiological crop maturity (Bourland et al., 1997a).
COTMAN curves enabled some conclusions to be made on the utility of the system in comparing cultivars of differing maturity to determine if the trend towards breeding for early maturity in Turkmenistan has led to cultivars that cut-out too early in the season.

It was also found that increasing number of irrigations from one to three (each 1 ML/ha) during the season more than doubled fibre yields and improved fibre quality. However, increasing number from three to five (five is the standard number of irrigations for the country) did not significantly improve either yield or quality. The potential benefits of reducing irrigation in Turkmenistan by 40% are considerable.
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The work presented in this thesis is original and my own work except as acknowledged in the text. I hereby declare that this thesis has not been submitted to any other institution for a degree award.

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CHAPTER 1 INTRODUCTION

Turkmenistan is part of the geographic region known as Central Asia, a vast area of desert, steppe and mountain ranges stretching from the Caspian Sea in the west to Mongolia in the east, from the Siberian forests in the north to the Hindu Kush and the Tibetan plateau in the south. Turkmenistan is the most southerly of the Central Asian states, bordered by the Caspian Sea on its west, Iran and Afghanistan to the south and with Kazakhstan and Uzbekistan on its northern border (King 1996). Turkmenistan covers 488,100 km², with over 80% being desert. The climate is sharply continental with average monthly temperatures -4°C in January to 28°C in July. The Karakum Canal brings water to most of the agricultural areas of the country, crossing 1,000 km of desert from the Amu Darya river on Turkmenistan’s north-eastern border (King op. cit.)

The history of Central Asia is linked to Soviet expansion, initiated by the conquest of Tashkent in 1865 (Hopkirk, 1990). Soviet systems of government and administration continue to some extent in all Central Asian States. The State exercises considerable control over the economy as well as the daily lives of its citizens, with substantial effect on agricultural practices and thus the scope for improvement through research and innovation. State payment to farmers and collectives for seed cotton is dependent on state ‘norms’ in agronomic practices being reported during the growing season.

This thesis reports work in Turkmenistan, funded by the European Union TACIS program (Technical Assistance to the CIS or Commonwealth of Independent States), with the broad aim of improving cotton production in that country. Cotton has been grown in central Asia for over 2,000 years. Prior to the Russian Revolution all cotton cultivars belonged to the
species *Gossypium herbaceum* and produced low yields of short staple cotton. Long staple *Gossypium barbadense* from Egypt was introduced in Ashgabat in the period 1905-1909. Medium staple *Gossypium hirsutum* was introduced into the country from the 1920s and today has become the dominant species, currently cultivated on around 80% of the cotton growing area in Turkmenistan (State Committee of Turkmenistan for Tourism and Sport, Turkmenistan, 2000). In 1999, the industry contributed 32% of the gross domestic product of the Turkmen economy (Economist Intelligence Unit, 2002.). An area of 770,000 ha of cotton was planted in 2001 and under 700,000 ha in 2002. Wheat and cotton, occupying about 90% of the irrigated arable land, are produced under a ‘state order’ system of subsidized inputs and monopoly rights to buy all production (Regional Agricultural Reform Program ‘RARP’ – Turkmenistan, 1998).

Yields of seed cotton have been declining since independence (RARP, 1998) and were below 2 t/ha in 2001 when the TACIS program began. Low temperatures marked the start of the 2002 season and rain delayed planting in many areas, producing a record low harvest with State average yields of less than 1 t/ha.

The political system under which the TACIS project was implemented provided significant boundaries within which improvement could occur, and provided important context for this thesis. The state order system does not provide farmers with an incentive to produce high yields of good quality cotton fibre. There is a shortage of both machines and labour for picking. Cotton research is under-resourced and research stations are poorly maintained. Researchers have little contact with the international community or access to information from other countries.
Experience in Turkmenistan indicates that the main factors determining seed cotton yields are: quantity of irrigation water applied, largely determined by frequency of application; nitrogen fertilization; sub-soiling or deep ploughing and plant population (Professor O. Regipov, Land and Water Institute, Ashgabat, pers. comm. 2002). Of these, the first two depend on State inputs and are closely controlled by local authorities. Thus there is no immediate scope for improvement here. The third requires cultivation equipment held collectively rather than individually. Hence of the four important factors, plant population is the only one that individual farmers can control.

The relationship between plant population and yield of cotton has been investigated in Turkmenistan over many years (Fursov, 1961; Bakasov, 1977; Kudratullaev, 1981; Kudratullaev et. al., 1981; Kurbangeldiev, 1985). In general, these studies have indicated that plant populations of 100-110,000 plants/ha gave maximum yields, although this may increase to 180,000 plants/ha for long staple cultivars under certain conditions (Kudratullaev, 1981).

Studies on the relationship between plant population and yield of cotton ceased in the 1980s, symptomatic of a general decline in cotton agronomy research in the country. Plant breeding efforts, however, continued and a suite of new long staple and medium staple cottons were produced in Turkmenistan in the 1980s (Chapau et al., 1990) that are currently being used on large areas of the country. These new cultivars incorporate the features of determinate growth and rapid maturity that may make them quite different to older cultivars (Babaev, 2001). As there is an important interaction between cotton genotype and plant populations in determining yield (Johnson and Walhood, 1972) new optimum plant populations should be decided for these new cultivars, rather than using recommendations based on older cultivars.
Anecdotal reports of low populations in commercial cotton crops were supported by measurements of low population in seed production fields during early June 2001 at the two Government farms on which the TACIS Project was located. Populations were recorded of 38,741 plants/ha for the medium staple cultivar ‘Ahal 1’ at ARPEC (Agriculture and Research Production Experimental Centre, Anau, Turkmenistan) and 50,963 plants/ha of the long staple cultivar ‘Iolatan 5’ at CRI (Cotton Research Institute, Iolatan, Turkmenistan). These were one half or less than those found to be optimum in studies on other cultivars previously conducted in the country (Kurbangeldiev, 1985). Visual inspection of commercial crops beyond the research stations suggested similar results. This could mean that plant populations generally are much below optimum, or that farmers have determined populations that are indeed optimal for the cultivars and agronomic conditions that now prevail in Turkmenistan.

Given these observations of field populations that are low by international standards (Kerby et al., 1987a; Baker, 1976; Bilbro, 1972; Ehlig et al., 1971; Fowler and Ray, 1977; Galanopoulou-Sendouca et al., 1980 and Verhalen and Williams, 1992), the changes in plant type since ‘optimal’ populations were determined (Bourland and Oosterhuis, 2001), and given the constraints under which technological improvement can occur in this state, it was decided to focus on plant population as the theme for this thesis. If low plant populations are to be found throughout the country, it is important to decide if the plant populations observed are appropriate for the new cultivars developed in Turkmenistan or if they were in fact sub-optimal.

In relation to the aims of the TACIS program to increase cotton production, changing plant populations would require none of the structural changes involved in changes to irrigation frequencies (determined by the state) or supply of state subsidized and controlled fertilizers.
Moreover, yield increases of 12% have been reported in other countries from increasing plant populations from 50,000 to 150,000 plants/ha (Kumar, 1988). Increasing plant populations from those observed in 2001 to those suggested by earlier work undertaken in Turkmenistan may be well worth the minor efforts involved.

The aim of the research described in this thesis was to improve cotton production in Turkmenistan through optimizing plant population. The first step was to determine if the plant populations measured at two government farms in June 2001 represented cotton field plant populations throughout the main cotton growing areas. Subsequent field experiments aimed to determine the optimum plant populations for newer medium staple cultivars like Ahal 1 and Iolatan 7 and long staple cultivars like Iolatan 5, 9938E and Ashgabat 97. Further experiments were undertaken with the aim of understanding why populations are so low, with a view to developing recommendations that may improve cotton yields via manipulating plant population.

Extensive factorial experiments carried out in the 1970s in Turkmenistan across a number of regions (Rejepov and Kudratullaev, 1979) determined the optimum irrigation amount for the medium staple ‘standard’ cultivar S133 was 5-5.5 ML/ha. These experiments were conducted in the heyday of Soviet cotton cultivation in Central Asia when water was relatively abundant. In Turkmenistan in the 21st Century, water restrictions due to environmental factors, the struggle for advantages in riparian rights in Central Asia and an increasingly high water table, all provide a need to re-examine cotton water requirements for optimum yields. This thesis therefore reports the results of a factorial experiment on the effect of plant populations at a number of irrigation frequencies on yield and phenology of cotton and an experiment on the effect of irrigation frequencies on the yield, maturity, quality and phenological characteristics of cotton.
The research was set within the phenological framework of the ‘COTMAN’ crop monitoring system (Oosterhuis et al., 1996a,b,c) which allowed the relationship between treatments (population, irrigation, row spacing) and effects (crop yield, maturity) to be examined in terms of crop phenology. The COTMAN system allows variables that affect plant phenology to be measured indirectly. This system could therefore be used in this research to substitute for equipment needed to measure such variables (e.g. photosynthetic photon flux densities) directly that was unavailable in Turkmenistan at the time this research was being conducted and that import restrictions prevented the TACIS programme from bringing into the country.

By developing the COTMAN model for Turkmenistan, it was hoped that the local industry would be provided with an important management tool and that local cotton breeders and researchers would be given a valuable tool for their work.
CHAPTER 2 LITERATURE REVIEW

2.1 Importance of cotton cultivation

Cotton is currently the leading plant fibre crop worldwide and is grown commercially in the temperate and tropical regions of more than 50 countries (Smith 1999). Specific areas of production include the USA, India, China, America, the Middle East, Central Asia and Australia where climatic conditions suit the natural growth requirements of cotton (Smith 1999). The four cultivated cotton species embody considerable genetic diversity, but this is dwarfed by the entire genus whose 50 species have an aggregate geographic range that encompasses most tropical and subtropical regions of the world (Percival et al., 1999). In Turkmenistan cotton is the leading agricultural crop, with 770,000 ha planted in 2001 and around 700,000 ha in 2002 (TACIS 2002), and also the main export crop (Economist Intelligence Unit 2002).

Cotton is harvested as seed cotton and ginned to separate seed and lint. Long lint fibres are further processed by spinning to produce yarn that is knitted or woven into fabrics (Smith 1999). Ginned seed is covered in short fuzzy fibres known as linters. In most cotton producing countries linters are removed as first or second cut linters and seed is sown for succeeding crops with naked seed. In Turkmenistan and other Central Asian States seed is still widely sown with the fuzz attached (TACIS 1998). Lint attached to the seed coat of fuzzy cotton may limit contact with the soil, thereby affecting it’s ability to imbibe moisture and germinate (Kerby et al. 1996).
2.2 Taxonomy and varietal development in Turkmenistan

The genus *Gossypium*, to which all the world’s cottons belong, consists of 50 species of perennial xerophytes. They are frost sensitive short day plants, which grow in arid regions of the tropics and subtropics (Brubaker *et al.*, 1999). *Gossypium* species can be grouped into cytologically distinct groups based on similarities in chromosome size and structure called genomes (Brubaker *et al.*, 1999; Endrizzi *et al.*, 1985; Stewart, 1995). Two Asian species (*G. herbaceum* and *G. arboreum*) and two American species (*G. hirsutum* and *G. barbadense*) are cultivated. These are the true cottons, distinguished by possession of lint, which consists of seed hairs flattened in cross section when mature and greatly convoluted, allowing them to be spun (Brubaker *et al.*, 1999). Eight diploid ‘genomes’ are recognized, types A – G and K (Edwards and Mirza, 1979; Stewart, 1995) with the number of chromosomes or ‘genome number’ being thirteen (x=13). All cottons are diploid except New World (American) cottons that are tetraploid (Endrizzi *et al.*, 1985). Genomes are typically similar amongst close relatives and this is reflected in the ability of related species to form hybrids that display normal meiotic pairing and high F1 fertility (Brubaker *et al.*, 1999).

Central Asia has long been associated with research into cotton genetics, and the first taxonomist to elucidate the ploidy of the genus was the botanist Gavriil Semenovich Zaitsev (Fryxell, 1979), working in the Ferghana Valley in present day Uzbekistan (Trives and Vaughan, 1998). In 1928 he published ‘A contribution to the Classification of the Genus Gossypium L.’ which is the basis of the modern conception of cotton (Zaitzev, 1928) Zaitzev recognized the fact that the old World cottons were diploids (2n=2x=26) and the New World tetraploids (2n=2x=52). They were difficult to hybridize and only produced sterile hybrids (Zaitzev, 1928).
It is thought *G. barbadense* spread as race *brasiliense* to the Caribbean and Africa. Selection for the annual habit occurred separately in the two locations, giving rise to extra long staple superfine Sea Island and Egyptian cottons (Niles and Feaster, 1984). Modern cultivars of *G. barbadense* (long staple, Pima or Egyptian cotton) are grown in Egypt, Sudan, the USA, China and the CIS. Turkmenistan was the center for Soviet improvement of long staple cultivars (Chapau et al., 1990). The long strong fibres make this species ideal for specialized uses but its lower yield makes it less popular than *G. hirsutum* which accounts for more than 90% of the world annual crop (Brubaker et al., 1999). *G. barbadense* moved from its center of origin in Peru and Ecuador east to north east South America to form the race ‘*brasiliense*’ (Hutchinson, 1962). Modern elite *G. barbadense* cultivars developed from the Sea Island cottons of the coastal islands of Georgia and South Carolina and the West Indies (Hutchinson and Manning, 1945). The Sea Island industry of the United States had collapsed by the 1920s under the boll weevil, *Anthonomous grandis* Boheman (Niles and Feaster, 1984) but the Sea Island lineage has contributed to the modern extra long staple cottons via the Egyptian cottons developed in Africa (Hutchinson and Manning, 1945).

In the CIS ‘*brasiliense*’ cottons from South America were first planted around Tashkent and in the Fergana Valley (Uzbekistan), in Tutaishi (western Georgia) and Gokchai (Azerbaijan) in the early 1900s. These attempts were not successful, but those to introduce long staple cottons from Egypt in the period 1905-9 were. These cultivars were tested at Andijan, Namangan and Tashkent (Uzbekistan) and in Ashgabat, Turkmenistan. The plantings in Turkmenistan proved the most successful and an institute at Iolatan was set up in 1925 to produce long staple cotton cultivars. In 1933 Sea Island cottons from the USA that had undergone further selection in Egypt were introduced. The leading Russian geneticist N.I. Vavilov suggested that selection should be made amongst Egyptian cultivars to produce a more compact type. This resulted in the release of cultivar ‘2i3’ in 1936. In the period 1937-50 an emphasis on early maturity produced the cultivar
910-E. In the period 1951-1965 breeding for productivity, maturity and fibre characteristics produced the cultivars 5476-E, 5904-E, 8763-E and 9078-E. From 1966-78 further selection for *Fusarium* wilt tolerance produced 9647-E and 9155-E. From 1978-1991 further selection for black root rot tolerance produced Ashgabat 25, 9732-E and 9871-E (Chapau *et al*., 1990). Since Turkmenistan became independent of Russia, the Cotton Research Institute at Iolatan has developed the current cultivars of long staple cottons – for example Iolatan 5, 9938-E and Ashgabat 97 (Ministry of Agriculture, Turkmenistan, 2001). Long staple cottons have also been used in inter-species crosses with Turkmen cultivars of *G. hirsutum* to introduce higher fibre quality into cultivars of this species (Ministry of Agriculture, Turkmenistan, 2001). This technique has in general been a failure world wide but has had some success in Turkmenistan, notably in the cultivar Iolatan 16 (TACIS, 2002).

*G. hirsutum* differentiated into races *punctatum* and *latifolium*. *Punctatum* was carried to Africa where the annual habit emerged. *Latifolium* spread to SE Asia – the annual habit and short day character being retained (Niles and Feaster, 1984). Stocks of *latifolium* went back to the temperate United States where the annual habit persisted but not the short day character. From 1806 onward, as ginning practices improved, agronomically superior green-seeded ‘*latifolium’* accessions replaced the others (Niles and Feaster, 1984). This led to the development of four basic categories of upland cultivars – Acala, Delta, Plains, Eastern - whose modern derivatives now dominate the world industry (Brubaker *et al*., 1999).

In Turkmenistan upland cottons from the USA have been used to develop the current *G. hirsutum* cultivars. As Turkmenistan was designated the center of breeding activities for *G. barbadense*, but Uzbekistan for *G. hirsutum* in Soviet times, many of the *G. hirsutum* cultivars used in Turkmenistan up to independence from the Soviet Union were from Uzbekistan. Since independence Uzbek cultivars like ‘133’ have been crossed with other accessions in
Turkmenistan and selections made for early maturity and productivity (Professor A. Babaev, Senior Plant Breeder, Ahal Production and Research Experimental Center, pers. comm. 2001).

2.3 Development and phenology of the cotton plant – general

The cotton plant has perhaps the most complex structure of any major crop (Oosterhuis, 1990). Its indeterminate growth habit and its sympodial fruiting branch cause it to develop a four dimensional occupation of space and time which is difficult to analyze (Mauney, 1986). Plant development in cotton can be divided into five main stages according to production management (Oosterhuis, 1990): germination and emergence, seedling establishment, leaf area and canopy development, flowering and boll development and maturation.

The transition between stages is not always clear. During each stage the plant may have differing physiological requirements. The structure and developmental patterns of the cotton plant have been the focus of much detailed study over a period of many years (Baranov and Maltzev, 1937; Brown and Ware, 1958; Dennis and Briggs, 1969; Mauney, 1984; Tharp, 1960). The physiology of the cotton plant is described in Carns and Mauney (1968); Eaton (1955); and Mauney and Stewart (1986). More recent reviews expand this knowledge to include detailed descriptions of the flowering patterns of cotton and the consequences of its physiological decline or ‘cut-out’ (Kerby and Hake, 1996; Oosterhuis and Jernstedt, 1999; Cothren, 1999).

Cotton has a distinctive and predictable flowering pattern (Munro, 1987). The first flowers to open are low on the plant, usually on main stem nodes six or seven, and on the first position on the fruiting branch (Bourland et al., 1992). About three days elapse between the opening of a flower on a given fruiting branch and the opening of a flower at the same relative position on the
next higher branch. The time interval for the development of two successive flowers on the same branch is about 6 days. The order is thus spirally outward and upward.

The regular phenology of the cotton plant has lent itself to descriptions such as the ‘composite plant diagrams’ of Munro and Farbrother (1969), the ‘uniform stage description’ devised by Elsner et al. (1979) and that used by Kerby et al. (1987) to describe the growth and development of Acala cottons. It has also meant that practical systems of plant monitoring can be devised that take into account this distinctive pattern of growth (Kerby and Hake, 1996). One of these, the ‘COTMAN’ system developed at University of Arkansas (Bourland et al., 1992; Bourland et al., 1994; Bourland et al., 1997a; Bourland et al., 1997b) is described later in this thesis in more detail.

The regularity of phenological events (especially flowering) in cotton has led researchers to study the unit of time corresponding to the interval between two successive similar periodically repeated events – referred to as the ‘plastochron’ (Michilini, 1958). Zaitsev (1927) in a similar manner considered time intervals between successive stages of growth to be divided into ‘isophases’ - the isophase being equal to the plastochron for the main stem, with multiples of the plastochron to describe time intervals between unlike events. In otherwise comparable conditions these intervals are fairly constant over a wide range of photosynthetic supply values such as might be produced under a range of naturally occurring light energy values (Huxley, 1964).

There are good reasons why intervals between events within and between sympodia differ (Hesketh et al., 1972). Events on the main stem are associated with initiation of leaf primordia on the shoot apex. Events within a sympodium involve the production of a floral bud, flower, open boll, a prophyll, a leaf, two internodes, and new axillary buds in the leaf axil in the prophyll axil (Mauney, 1968). The growth of this fruiting branch unit exclusive of the flower or boll then
ceases, with the production of a new floral unit coming from the axillary bud of the leaf, or occasionally the prophyll - as many as seven such floral units have been found within a sympodium (Hesketh, et al 1972).

Working in the Ferghana Valley of the former Soviet Union (now in Uzbekistan) Zaitsev (1927) studied the effects of temperature on most isophases that occur in the seasonal cycle of the cotton plant. He hypothesized that two isophases were needed for each of the three growth intervals in cotton - planting to expansion of cotyledons, cotyledon expansion to expansion of first true leaf and the interval between similar events on a fruiting branch. Hesketh et al. (1972) tested Zaitsev’s hypothesis in the phytotron. They found that Zaitsev’s values of one isophase between leaves on the main stem (2.5-3 days) and four isophases from planting to expansion of the first true leaf (10-12 days) held fairly well at mean temperatures of 26.5°C, but not at lower temperatures.

For the date of the first floral bud (‘square’ in the USA and Australia), days from development of first floral primordial (‘squaring’) to flowering, and the boll period (days from flowering to boll opening) the fruiting map of the plant generated by Hesketh et al. (1972) with squares developing every isophase/plastochron on successive sympodia up the main stem and occurring around two isophases within a sympodium is in striking agreement with the earlier work of cotton scientists like Zaitsev (1927) and Mauney (1966) and is borne out in the monitoring systems developed by later researchers and used by hundreds of cotton farmers in the United States (Bourland et al., 1997a; Bourland et al., 1997b; Lamers, 1996; Oosterhuis et al., 1996a; Oosterhuis et al., 1996b; Oosterhuis et al., 1996c).
2.4 Growth habit and development of individual parts

2.4.1 Cotton seed, its germination and emergence

Cotton seed is ovoid, somewhat pointed and surrounded by a seed coat and two well developed folded cotyledons. The epidermal layers of the seed-coat bear the fibres or lint. The embryo consists of a radicle, hypocotyls and poorly developed epicotyl. The cotyledons or seed leaves eventually form the first green leaves but initially contain stored food for germination (Oosterhuis and Jernstedt, 1999). There are generally ten acid delinted seeds per gram (McCarty and Baskin, 1992). Germination begins with the entry of moisture within the first few hours through the chalaza and later through all parts of the seed coat (Association of Official Seed Analysts, 1983). With continued expansion of the hypocotyls, the cotyledons and epicotyl are pulled from the earth (Association of Official Seed Analysts, 1983). The seed coat is often shed and remains in the soil. Soil crusting may hinder emergence of hypocotyls and cotyledons (Oosterhuis and Jernstedt, 1999).

Capping of soils is common in cotton growing areas where winds are frequent or in fields that have a rough loose surface (Kerby et al., 1996a). Soil is mounded several inches above the flat surface of the drill row to conserve moisture until the radicle emerges. As soon as cotton is in the ‘crook’ stage when the hypocotyls begins to elongate, the field should be un-capped because the danger of desiccation will have passed. Uncapping requires a trip through the field and can pose problems if rain occurs (Kerby et al., 1996a).

Another factor influencing established plant populations and seed germination alike is soil impedance – resistance to root or hypocotyl elongation (Kerby et al., 1996a). Soil impedance determines how hard the seedling hypocotyls or ‘shank’ must push on the cotyledons to move
them through the crusted surface layer of soil (Association of Official Seed Analysts, 1983). Although some soil impedance is beneficial for shedding the soil coat from the cotyledon, severe impedance (such as that associated with alkali crust) can restrict the seedlings ability to emerge (Kerby et al., 1996a).

Germination is favored when there are soil temperatures above 18ºC; this is the ‘critical’ temperature for cotton seed germination and is used in the laboratory for the ‘cold test’ for cotton seed vigor (Association of Official Seed Analysts, 1983; McCarty and Baskin, 1992; McCarty and Baskin, 1993). Field emergence will depend on a combination of values of germination tests and accumulated degree days five days after planting (Kerby et al., 1987b; Kerby et al., 1989). In both Arkansas and Australia it is recommended that growers wait for three consecutive days of minimum soil temperatures of 14ºC at 5cm before sowing (Bonner, 1990; Buxton et al., 1976; Constable and Shaw, 1988).

In Turkmenistan, Dr. Sergei Kanoply is attempting to develop cold-tolerant cultivars from material selected following early planting on approximately 1st March (compared to the usual practice of planting on the 15th April). A cold tolerant line from USA, Tamcott S37, is used as a control. Some local lines are claimed by Dr. Kanoply to be better than the control (National Institute of Agricultural Botany, 2002).

2.4.2 Acid de-linting

It has long been established that acid de-linting seed improves germination both in the laboratory and the field (Christidis, 1936). Studies conducted in South Africa over a ten-year period indicate that these germination increases are often accompanied by yield increases (MacDonald et al., 1947). Increased germination is associated with removal of fuzz and also separation of
chemically treated seeds into ‘sinkers’ and ‘floaters’ – the later having poorer viability and being removed in the treatment process - and the control of bacterial and fungal diseases of the young cotton plant (Hansford et al., 1933; MacDonald et al., 1947). Germination tests carried out on acid-delinted ‘sinkers’ and floaters’ of seed of both G. hirsutum (Ahal 1) and G. barbadense (Iolatan 5, Iolatan 97, E9938) cultivars in Turkmenistan in 2002 confirm these findings for Turkmen cotton cultivars (National Institute of Agricultural Botany, 2002b).

‘The role of the presence of hydrophobic fuzz or lint in inhibiting water uptake in cotton seed was demonstrated in experiments conducted by Marani and Amirav (1970) on acid de-linted seed in which F1 (parental seed coat) and F2 (F2 embryo and F1 seed coat) reciprocal progenies had significant differences between F1 but not F2 reciprocal crosses in the amount of water the seed imbibed. This indicated that differences in germination of reciprocals was not due to embryo effects but to maternal tissue effects related to the amounts of seed coat fuzz.’

Development of the technology of small scale acid delinting plants for experimental institutes will mean that industries like Turkmenistan’s can introduce acid delinting on a small scale without the need for large costly commercial scale plants (Doitsinis and Baziotis, 1998).

2.4.3 Roots

After emergence the cotyledons are carried a few centimeters above the soil by the expanding hypocotyls before expanding and unfolding. The cotyledons become green on exposure to light and are capable of photosynthesis (Dennis and Briggs, 1969). Much of the early development of the plant takes place in the roots while growth of the first true leaves is relatively slow. The radicle or primary root is the first organ to emerge from the seed (Dennis and Briggs, 1969). The primary root penetrates the soil rapidly and may reach 25 cm by the time the cotyledons unfold. Root development during early vegetative growth may proceed at 1-5 cm/day (McMichael,
The taproot penetrates from depths of 1m to up to 3m while lateral roots remain fairly shallow – less than 1m (McMichael, 1990). Root length then declines as older roots die and root activity declines as boll load develops and carbohydrates are increasingly directed to bolls (Oosterhuis, 1990).

### 2.4.4 Stems and branches

The cotton plant has a prominent main stem or primary axis, which results from the elongation and development of the terminal bud or apical meristem (Oosterhuis and Jernstedt, 1999). The main stem consists of a series of nodes and internodes and has an indeterminate growth habit. Branches develop from a bud located in a leaf axil (Oosterhuis, 1990). Two types of branches are produced, vegetative or monopodial and fruiting or sympodial (Bourland et al., 1997a, 1997b).

Vegetative branches are structurally like the main stem – growth is from a single terminal bud (monopodial) and they bear flowers and fruit only after re-branching. Fruiting branches are produced by the main stem and vegetative branches and grow at an acute angle to the main stem (Bourland et al., 1997a). They normally arise from the main stem near the ground and tend to grow in an upright position. Generally only one monopodial branch per plant develops, however damage to the terminal bud on the main stem will increase the number of vegetative branches that develop (Brown and Ware, 1958).

When a fruiting branch develops from the main stem a prophyll, a true leaf and a bud or ‘square’ form at the same node (Baranov and Maltzev, 1937). Elongation of the inter-node behind the square and leaf causes these organs to be extended from the main stem. This branch terminates in a square and a second leaf and square develop in the axil of the first leaf and similarly extend from the first leaf and square by inter-node elongation. This process is repeated forming several squares, internodes and leaves in a typical zig-zag pattern (Tharp, 1960).
2.4.5  Leaves and the crop canopy

Cotyledons, prophylls and true leaves are three types of leaves (Mauney, 1984). The kidney-shaped cotyledons are less than 1 cm wide. The prophylls are small and inconspicuous without a stipule and resemble a petiole (Mauney, 1984). True leaves vary in size and shape from entire to deeply lobed (Mauney, 1984). First true leaves are generally heart shaped and leaves have a thick waxy cuticle with numerous stomata and epidermal and glandular hairs on the surface (Oosterhuis, 1990). True leaves are developed from primordia on the terminal growing point initially located between cotyledons and later from axial buds on the main stem (Dennis and Briggs, 1969). Initially slow to grow compared with the roots, one month after planting only four to five true leaves are unfolded and visible (Brown and Ware, 1958). However, by the time the first true leaf unfolds the plant has already developed six to seven more leaf initials in the apical meristem (Brown and Ware, 1958). The leaves, like the branches, are spirally arranged on the stem in a 3/8 phyllotaxy; each new leaf a 3/8 turn clockwise or counter-clockwise above the last (Oosterhuis, 1990).

True leaves can be further divided into main stem leaves, which arise from the main stem and sympodial leaves which arise from fruiting or sympodial branches (Oosterhuis, 1998). Main stem leaves are associated with development of the main stem and roots, as well as bolls developing at first node (‘MN1’ or main-stem node one) along the fruiting branches. Sympodial leaves are almost exclusively associated with boll development (Oosterhuis, 1998). Main stem leaves are the only true leaves present during the first four to six weeks after planting, after which the sympodial leaf area increases rapidly and exceeds the main stem leaf area soon after first flower (Mauney, 1984). Average life of a leaf is around 65 days and photosynthetic activity peaks about 20 days after unfolding and thereafter declines (Oosterhuis, 1990; Oosterhuis and Wullschleger, 1992).
Leaf area index (LAI), or the amount of leaf area of the plant per unit area of soil, increases slowly in the first 200-250 degree-days after planting but then more rapidly during early fruiting and canopy closure (Oosterhuis and Wullschleger, 1992). Canopy closure takes place when foliage just meets between rows, about 700-750 degree-days after planting in the southern USA (Oosterhuis, 1998). This improves weed control and decreases water loss from direct soil evaporation, however interplant competition commences shortly after adjacent plants make physical contact within and across the row (Maas, 1997). Main stem leaf area reaches a maximum prior to first flower and remains relatively constant thereafter whereas sympodial leaf area continues to increase and eventually constitutes about 60% of total leaf area (Mauney, 1984).

2.4.6 Floral buds (‘squares’) and flowers

‘Reproductive growth commences about 425-475 degree-days after planting with the formation of the floral buds in the apical part of the plant.’ This is followed 300-350 degree-days later by flowering (Oosterhuis, 1990). Due to indeterminate development some vegetative growth continues at the same time as reproductive development for the rest of the season. The physiology of the plant at this stage is associated with photosynthesis and carbon partitioning to the developing fruit (Constable and Rawson, 1980a,b; Oosterhuis and Wullschleger, 1992).

Floral buds appear first as small green pyramidal ‘squares’. These are comprised of three large green bracts (epicalyx) completely enclosing the growing flower. Immediately inside the bracts is the fused calyx ring (sepals), which tightly encloses the base of the five conspicuous petals, collectively forming the corolla (Mauney, 1984). Initially the bracts are all that are visible of the square (Mauney, 1984). Under conditions in the short season regions of the USA, first squares
are visible about 35 days after planting and the first flowers around 21 days later (Bourland et al., 1997a). New squares appear in the terminal of the plant at about three day intervals and appear on each fruiting branch at about six day intervals Bourland et al., 1997a).

The cotton flower is white for *G. hirsutum* on the day it unfolds (yellow for *G. barbadense*) but the petals turn pink-red the following day and abscise at their base (Oosterhuis, 1990). They usually fall off within a few days but can remain trapped by the bracts and boll as dried vestiges (Baranov and Maltzev, 1937).

Cotton has a distinctive and predictable flowering pattern (Bourland et al., 1992). The first flowers to open are low on the plant, usually on main stem nodes six or seven and on the first position on the fruiting branch (Bourland et al., 1992). About three days elapse between the opening of a flower on a given fruiting branch and the opening of a flower at the same relative position on the next higher branch. The time interval for the development of two successive flowers on the same branch is about six days (Hesketh et al., 1972; Mauney, 1966). This period will be fairly constant over most of the flowering cycle but will vary a little late in the season (Mauney, 1986; Kerby et al., 1987) due to genotype and environment (Hesketh et al., 1972). Data from Californian experiments conducted by Kerby and Hake (1996) on 11 Pima (*G. barbadense*) and 34 Acala (*G. hirsutum*) cultivars indicate no difference between cultivated cotton species in these time periods. The order of flowering is best described as spirally outward and upward (Oosterhuis et al., 1996b). Flowers continue to be produced until defoliation, frost or physiological cutout (Bourland et al., 1992).
2.4.7 Pollination and fertilization

The flower opens as a white flower (*G. hirsutum*) at dawn and pollination transfer of pollen from anthers to stigma occurs within a few hours (Oosterhuis, 1990). Flowers are self-pollinated although some insect pollination may occur.

The fruit of the cotton plant is called the boll. It is generally a spherical or ovoid leathery capsule light green in color with a few pigment glands (Mauney, 1986). The boll grows rapidly after fertilization following a sigmoid curve pattern - most rapid growth occurs after 7-18 days and full size is reached in 20-25 days (Oosterhuis, 1990). Maturation of boll from anthesis to opening (carpel dehiscence) takes about 50 days. This period can be substantially lengthened with cool temperatures at the end of the growing season (Galanopoulou-Sendouca, 2002). At maturity the capsules (also known as ‘burs’) crack or split along their sutures and the mature white seed cotton within expands rapidly pushing out beyond the capsule forming a white fluffy mass divided into locks (Kerby *et al.*, 1992). Each boll typically weighs 4-5 grams for *G. hirsutum* and 2-3 g for *G. barbadense* (Galanopoulou-Sendouca, 2002).

2.4.8 Maturity and defoliation

‘Cutout’ occurs when the boll load (sink) consumes all carbohydrate produced by leaves (source). This is affected by both early boll load and the quantity of leaf area to sustain boll load (Kerby and Hake, 1996). The distribution of bolls on the plant varies due to abscission from physiological and environmental causes (Guinn, 1982b). A large percentage of the total yield is derived from the central portion of the canopy (Mauney, 1984; Bourland *et al.*, 1992; Boquet *et al.*, 1994; Jenkins *et al.*, 1990a,b).
Leaf abscission at maturity is a physiological process that involves an active separation of living tissue from the plant (Cathy, 1986) and is essential before leaf drop can occur. Abscission occurs at the base of the leaf petiole in an area called the abscission zone (Addicott, 1982). This is structurally distinct and consists of a layer of one or more layers of thin-walled parenchyma cells resulting from anti-clinal divisions across the petiole, except in the vascular bundle (Addicott, 1982). The abscission zone through which the fracture occurs contains the same cell classes as adjacent tissues (Sexton and Woolhouse, 1984); however wall breakdown is usually confined to a separation layer one to three cells wide in a 5-50 cell-wide zone. Cells in the zone are generally smaller than their counterparts in adjacent tissue (Cothren, 1999).

Cotton is an inherently perennial crop grown annually. The crop has a natural mechanism for shedding mature leaves, although this does not necessarily synchronize with the best time for harvest from the producer’s viewpoint (Cothren, 1999). As leaves and bolls on individual plants move towards maturity the farmer has to make a decision as to when to defoliate his fields to expedite mechanical harvesting (Williford et al., 1986).

One basis for timing defoliation is related to plant maturity and development and is described by Kerby et al. (1992) as the ‘nodes above the cracked boll’ or ‘NACB’ technique. This technique depends upon experimental evidence that individual bolls are not affected by defoliation if they were less than four nodes above the cracked boll – reduction in boll size began at NACB=4. Acala strains of G. hirsutum cottons are typically mature when they have 11-12 fruiting branches. This is the same development reported in Delta strains of G. hirsutum cottons by Jenkins et al. (1990a,b).
2.4.9 Fibre growth and development

Cotton fibres arise by the growth and differentiation of the outer ovule epidermal cells at or near the day of anthesis. They are visible as swellings of the epidermal cells at the time of anthesis. Seeds attain their full size about three weeks after fertilization but do not reach maturity until the boll opens (Benedict, 1984). The fibre cells elongate for about 27-39 days past anthesis (‘dpa’); and maximum growth takes place at 10-15 dpa (Schubert, 1975). There are two stages in fibre development – elongation and secondary thickening (Oosterhuis, 1990). There is an overlap in the formation of the primary and secondary walls of the fibres and the secondary wall is formed from 17-53 dpa, at which stage the boll is mature, depending on species, cultivar and environment (Benedict et al., 1973). The fibre elongation period involves the synthesis of primary wall, plasma membrane, internal membranes, cytosol and organelles, whereas the growth of the secondary walls involves the synthesis and deposition of cellulose in a spiral fashion on the inner wall (Schubert et al., 1973). The extent of the elongation period determines the fibre length – this is a linear measurement ranging from 25-34mm (Benedict et al., 1999).

Degree of thickening and angle of spirals affect fibre length and maturity. Until the boll opens the fibre is a living cell, but upon opening, the fibre is exposed to the air and soon dries out and becomes twisted (Spinlab, 1998). In addition to long fibres, most commercial cultivars of G. hirsutum, but not G. barbadense, have short white or colored fibres on the seed called ‘linters’ or ‘fuzz’ fibres (Benedict et al., 1999). Cotton fibre quality as defined by the characters length, maturity, strength and micronaire is largely determined by genetics but may be influenced by climatic conditions - bolls maturing late in the season when temperatures are lower require a longer period for fibre growth and development and often produce less lint of poorer quality (Ramey, 1999).
2.5 Physiology of the cotton plant, senescence, cutout and nodes above the white flower
- ‘NAWF’

2.5.1 Physiological explanations of cutout

Decreases in growth, flowering and boll retention of cotton occur during the season in many modern cultivars even though it is an indeterminate plant. If these changes are pronounced, they are often referred to as ‘cutout’ (Guinn, 1985b). Cotton is defined as being in the cutout stage when pronounced decreases in growth, flowering and boll retention occur (Patterson et al., 1978). If cutout occurs too early it may decrease yield. Conversely, the complete and permanent cutout at end of season would facilitate the control of insect pests and increase crop harvestability (Guinn, 1985a; Kittock et al., 1973). Cutout is strongly affected by boll load and may occur because of competition for photosynthate, a change in hormonal status, or both (Guinn, 1985a).

Guinn (1974) found that factors that decrease photosynthesis or increase respiration delay fruiting and decrease retention of squares and bolls and thereby affect cutout. Low light intensity could become critical with high plant populations (more than 100,000 p/ha), cloudy weather, excessive vegetative growth or a combination of the above conditions.

Ehlig and Le Mert (1973) and Patterson et al. (1978) demonstrated that as a plant becomes loaded with fruit or bolls, subsequent boll retention, growth and flowering rate decreases. This suggests that cutout is initiated by competition for photosynthate. Guinn (1985b) manipulated the reproductive photosynthetic demand by removing flowers set early in the season. His results support the view that cutout is largely related to competition for photosynthate.
The premise that competition for photosynthate is the cause of cut-out is confounded by the fact that leaf and canopy photosynthesis decrease markedly at cutout (Constable and Rawson, 1980a; Peng and Kreig, 1991; Wells, 1988; Wullschleger and Oosterhuis, 1990a). However, in the experiments conducted, photosynthesis of young leaves also decreased as the canopy aged (Constable and Rawson, 1980a; Peng and Kreig, 1991; Wullschleger and Oosterhuis, 1990a). Therefore a physiological change must occur even in young leaves as the plant starts to cutout. The decline in photosynthetic activity at cut-out may be due to a relocation of leaf nitrogen, particularly from the plant hormone rubisco, to meet the high nitrogen demand of seeds developing in maturing bolls (Pettigrew and Meredith, 1997). Moreover, studies have shown a strong relationship between leaf nitrogen concentration and photosynthesis (Wullschleger and Oosterhuis, 1990b).

In summary, complex and as yet poorly understood interactions between hormones and competition for organic and inorganic nutrients are likely to influence the onset of cut-out.

### 2.5.2 Nodes above the White flower (‘NAWF’) as indicator of cut-out

The relationship between the number of nodes above a first position white flower (NAWF) and canopy photosynthesis has been outlined by Bourland *et al.* (1994) for short season cotton areas of the USA. As NAWF decreases, canopy photosynthesis decreases (Bourland *et al.*, 1992a,b). The relative yield contribution of flowers declines if produced within five nodes of the plant apex and at NAWF=5 the plant is at or near cutout (Bourland *et al.*, 1994). The proposition that NAWF=5 is a ‘signal’ that cutout has occurred in *G. hirsutum* cultivars under short season conditions has also been verified by Torrey *et al.* (1996) and Karner and Goodson (1998).
Work conducted in 35 Acala (*G. hirsutum*) fields and 11 Pima (*G. barbadense*) fields in 1990-1992 by Kerby and Hake (1996) suggest that the relationship between vegetative and fruit growth is different for the two species. Cutout occurs when NAWF averages 5.0 for *G. hirsutum* and 3.5 for *G. barbadense* (the *G. barbadense* flower is usually yellow, rather than white).

Similarly, very long season conditions in some Australian cotton areas may indicate that cutout could be reached at NAWF=4, rather than NAWF=5, although some Australian researchers still use NAWF=5 to define cutout (G. A. Constable, Cotton Research Institute, Narrabri, pers. comm. 2003).

2.5.3 Validation of NAWF=5 and the COTMAN system and NAWF used to explain earliness response to N rates

The crop-monitoring program COTMAN is based on the concept of NAWF being an indicator of cutout and physiological crop maturity (Bourland *et al.*, 1997a,b). COTMAN uses the concept of 350 HU (heat units or ‘degree days’) after anthesis of the last effective flower population at NAWF=5 being used for termination of insecticide application in the short season environment of Arkansas, USA (Bourland *et al.*, 1994; Cochran *et al.*, 1995, Cochran *et al.*, 1998).

‘COTMAN’ as a system of crop monitoring and management is based on a detailed body of knowledge built up over ten years in the specific environment of short season cotton growing areas in Arkansas (Bourland *et al.*, 1990; Bourland *et al.*, 1992a,b; Bourland *et al.*, 1994; Bourland *et al.*, 1997a,b; Cochran *et al.*, 1995; Cochran *et al.*, 1998; Oosterhuis, 1990; Oosterhuis *et al.*, 1992; Oosterhuis *et al.*, 1993; Oosterhuis *et al.*, 1996a; Oosterhuis, 1998; Oosterhuis, 2001).
As the system has only recently been refined to the extent that farmers can use it as a crop monitoring system, limited opportunity has been available for the system to be verified experimentally (Prof. D.M. Oosterhuis, pers. comm. 2003). It has been reported that terminating insecticides at 350 HU after NAWF=5 results in higher yield than when terminating at either before or after 350 HU (Oosterhuis et al., 1996). Using the physiological implications of COTMAN, it was hypothesized that insect damage to the upper canopy (above NAWF=5) would result in partitioning of carbon to lower developing bolls (Kim and Oosterhuis, 1998).

Experimental studies carried out by Oosterhuis et al. (1999) using $^{14}$C labeling were conducted to test the hypothesis. Removal of fruit by hand in this experiment simulated insect damage. Differential movement of $^{14}$C observed in the study supported the hypothesis that available carbohydrates from the upper canopy source leaves were translocated to alternate sinks such as bolls developing in the lower part of the canopy and therefore the COTMAN concept of insect termination at 350 HU after NAWF=5 (Bourland et al., 1994; Cochran et al., 1995, Cochran et al., 1998) was experimentally verified.

Bondada et al. (1996a) provided additional verification of the COTMAN system by measuring NAWF for soil nitrogen application rates and conducting linear regression of NAWF with DAP for each soil N rate. The resultant delays in crop maturity, measured by NAWF, with increased soil nitrogen discovered in this study were in agreement with experimental studies carried out by McConnell et al. (1993).

Days after planting to NAWF=5 has been used to measure crop earliness and maturity (Bourland et al., 1992) and NAWF is a plant indicator that predicts cutout based on the balance between vegetative and reproductive growth (Bourland et al., 1992; Oosterhuis et al., 1992). Cotton with the highest N rate in the study conducted by Bondada et al. (1996a) reached NAWF=5 later than all three low N rates and the 0 treatment reached NAWF=5 earlier than all three higher N rates.
This earliness in nitrogen deficient cotton plants has been associated with accelerated leaf senescence, a shorter flowering period and appearance of the first fruiting node at a lower main stem node (Ray and Richmond, 1971; Munro, 1971).

In another study conducted by Bondada (1994), using $^{15}$N accumulation in various canopy strata, canopy photosynthesis was found to be strongly influenced by soil nitrogen and was correlated with NAWF and yield. The middle layer had higher $^{15}$N accumulation due to higher boll load and increased leaf area, in accordance with similar findings reported by Mullins and Burmester (1990). Further studies by Bondada et al. (1997) indicated that the capsule wall was a reservoir of $^{15}$N when the bolls were young, but as they matured lint and seed became the major sinks and accumulated the majority of $^{15}$N. Increased epicuticular wax, coupled with leaf age, was associated with reduction in $^{15}$N absorption (Bondada et al., 1997).

More recent research further supports the use of COTMAN in explaining level of insect attack treatment differences in cotton maturity (Brown et al., 2001; Kharboutli, 2001).

2.6 Relationship between development and physiology - heat units and development

The cotton plant follows a genetically determined orderly pattern of growth (Munro and Farbrother, 1969). The development of the cotton plant in the vital stages of emergence and early growth is determined by temperature (Wanjura et al., 1970; Wanjura et al., 1973).

The crucial stage of the development of the cotton plant, the fruiting site cycle, begins with initiation of the first square on the first fruiting branch (Mauney, 1966). The square period, from when the flowering body is 3mm in size until flowering is 370 degree days (DD) or ‘heat units’ (HU) (Hesketh and Low, 1968; Hesketh et al., 1972). The boll period, or time interval from
flower to mature boll, is an exponential function of temperature (Mutsaers, 1976; Wanjura and Newton, 1981). The main stem node on which the first fruiting branch forms is influenced by a number of environmental and crop management factors, of which temperature is the most important (Buxton et al., 1977; Hesketh and Low, 1968; Mauney, 1966). Moraghan et al. (1968) found temperature rather than photoperiod to determine floral initiation in cotton.

Based on a degree threshold of 12°C (sometimes 15°C) above which the crop grows but below which there is little growth and development, daily temperatures can be used to understand the unfolding of the calendar of developmental events (Constable and Shaw, 1988). Calculation of heat units is by subtracting the threshold temperature from averaged maximum and minimum daily temperatures. When minimum temperatures fall below 12°C, a value of 0 is given to 

\[ DD = \frac{(T_{\text{max}} - 12)}{2} + \frac{(T_{\text{min}} - 12)}{2} \]

(Constable and Shaw, 1988)

Calculation of accumulated heat units (DD) and knowledge of DD for each growth stage can be used to predict the events in the annual cotton ‘calendar’. The number of growing degree days ‘DD’ or ‘HU’ to particular developmental events vary slightly with species, cultivar and other factors (Constable and Shaw, 1988), notably cold shock. The average DD requirements increase by 5.2 for each day that minimum temperatures are below 12°C. The temperature 12°C is referred to as the ‘base temperature’ and this has been determined under Australian conditions by consideration of the coefficient of variation in growing degree days at various temperatures (Constable, 1976) and by the ‘intercept method’ (Constable, 1976). Between planting and squaring and between squaring and flowering, DD are a more reliable measure of phenological development than calendar days (Constable, 1976). However, between first flower and first frost, the number of calendar days may be as reliable an indication as DD (Constable et al., 1976).
Heat units or DD required for developmental stages in cotton for southern USA (Oosterhuis, 1990) and Australia (Constable and Shaw, 1988) are given below:

**TABLE 2.1** Degree Days required for progress through developmental stages in cotton for southern USA and Australia (after Oosterhuis, 1990 and Constable and Shaw, 1988)

<table>
<thead>
<tr>
<th>Developmental stage</th>
<th>DD southern USA</th>
<th>DD Australia at 28º/20ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting to seedling emergence</td>
<td>50-60</td>
<td>80</td>
</tr>
<tr>
<td>Nodes up the main stem</td>
<td>45-65</td>
<td></td>
</tr>
<tr>
<td>Emergence to first square</td>
<td>425-475</td>
<td>425</td>
</tr>
<tr>
<td>Square to first white flower</td>
<td>300-350</td>
<td></td>
</tr>
<tr>
<td>Planting to first flower</td>
<td>775-850</td>
<td>777</td>
</tr>
<tr>
<td>White flower to open boll</td>
<td>850</td>
<td>750</td>
</tr>
<tr>
<td>Planting to harvest</td>
<td>2600</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 2.2** Days required from planting for progress through developmental stages in cotton for southern USA and Australia (after Oosterhuis, 1990 and Constable and Shaw, 1988)

<table>
<thead>
<tr>
<th>Developmental stage</th>
<th>Days in southern USA</th>
<th>Days in Australia at 28º/20ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination / radicle appearance</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Planting to seedling emergence</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Cotyledons unfolding</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Root depth 20-30cm</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>First true leaf unfolds</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Planting to first ‘pin-head’ square</td>
<td>35</td>
<td>42</td>
</tr>
<tr>
<td>Planting to second ‘pin-head’ square</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Planting to first white flower</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Planting to canopy closure</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Planting to peak flower</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Planting to first full size boll</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Planting to first open boll</td>
<td>110</td>
<td>128</td>
</tr>
</tbody>
</table>

Cotton crop management strategies should take the heat unit-based development of the plant into account to achieve optimum yields (Bourland *et al.*, 1997a). Zhang *et al.* (1994), for example, use the accumulated HU after true cutout date (NAWF=5) to determine the last date after which insecticide application is no longer profitable in short season areas of the USA.
2.7 Components of cotton yield

Ismail and Al-Enani, (1986) found in field studies that bolls per plant had the greatest contribution to yield. However, Guinn (1982a; 1985a) found that carrying capacity per plant (bolls per plant) varied inversely with plant population. Other experiments confirm that fruit production on an individual plant basis (squares, numbers of immature and mature bolls) is inversely related to plant population (Jones and Wells, 1997; Hoskinson et al., 1972; Mass, 1997; Wanjura and Bilbro, 1977). Weight of individual bolls may also decrease with increasing plant populations (Gannaway et al., 1995).

Combining these two important ways of measuring cotton yield (bolls per plant and weight of those bolls and plants per unit area) results in identification of the two major components of cotton yield: boll number per unit area and boll size or lint per boll (Cothren, 1999). Cotton lint yield components are therefore boll number per unit area, mean weight of boll including seed and lint and lint percentage or ginning out-turn (‘GOT’) (Galanopoulou-Sendouca, 2002).

2.8 Effect of changing cotton crop plant population on cotton yield

It is a common strategy employed by farmers to plant cotton where plant growth per plant is limited by short seasons, in order to more efficiently ‘harvest’ light, CO₂, water and soil nutrients (Fowler and Ray, 1977). Under very short season conditions densities as high as 200,000 plants/ha may be used in order to compensate for low production per plant (Kerby et al., 1996).

Ideal plant densities for maximum yields are also influenced by the cultivar planted (Kerby et al., 1990a,b). This conclusion appears valid regardless of the species used or the growing environment. It applies to G. barbadense, with a leaf type more sensitive to light penetration into
the canopy growing under the long season conditions of Arizona (Kittock et al., 1986), or ‘Acala’ cultivars of *G. hirsutum* under the wide range of management and experimental conditions reported by Kerby et al. (1996) in the shorter season of the San Jaoquin Valley, California.

Cotton cultivars have undergone considerable change worldwide since the 1960s (Meredith, 1998; Bourland and Oosterhuis, 2001). Optimum plant populations must be estimated anew for each generation of new cultivars, because genotype affects the cotton plant’s yield response to varying plant populations (Heitholt, 1994; Heitholt et al., 1992; Jadhao et al., 1993; Johnson and Walhood 1972; Jones, 1982; Kerby et al., 1990a,b; Mohamad et al., 1982; Smith et al., 1979; Wells and Meredith, 1984; Wells and Meredith 1986a,b; Wells et al., 1986). Bilbro (1981) conducted one of the few studies that failed to report a genotype effect of varying plant population on yield.

The introduction of new no-tillage cotton production systems both in southern Texas in the United States and in Australia also necessitated re-examination of optimum plant populations for new tillage methods (Segarra et al., 1991). Several researchers have found that conservation tillage is more profitable primarily due to reduced production inputs, but also due to increased water infiltration and storage under no-till systems (Segarra et al., 1991; Weise et al., 1994). Retained crop residues may decrease wind damage (Hagen and Armbrust, 1994) and water erosion (McGregor and Mutchler, 1992; Mutchler et al., 1985) and increase water infiltration and soil water retention (Bordovsky et al., 1994; Radford et al., 1995). Smart and Bradford (2000) also found that mechanical innovations such as new closing wheel configurations significantly affected plant populations with mouldboard tillage (the Dawn closing wheel with depth wheel cover plus conventional rubber wheel reduced yields) and lint yields under no-till
conditions (although there was a numerical reduction in plant populations, these were not significantly reduced).

2.9 Specific plant population effects on components of cotton yield

2.9.1 Overall response

The effect of plant population on the yield of cotton has been studied for over 100 years in the USA. Kittock et al. (1986) report the first scientific study on the relationship between plant population and yield of cotton taking place in 1866 in that country. The cotton science literature of Central Asia also indicates considerable interest in the effect of plant population on yield over three decades (Fursov, 1961; Bakasov, 1977; Bakasov et al., 1976; Kudratullaev, 1981; Kudratullaev et al., 1981; Kurbangeldiev, 1985). As field plant populations are relatively easy for both a private (in Australia or the USA) or collective farmer (Turkmenistan) to modify, this interest is entirely justified.

Experiments have reported maximum cotton yields in a range of populations from 50,000 to 250,000 plants/ha (Bilbro, 1981; Bridge et al., 1973; Fowler and Ray, 1977; Hawkins and Peacock, 1970; Hawkins and Peacock, 1971; Hawkins and Peacock, 1973; Smith et al., 1979). However, experiments with Acala cottons under short season conditions have found maximum yields in the more narrow range of populations from 86-111,000 plants/ha (Kerby et al., 1987a; Baker, 1976; Ehlig et al., 1971; Fowler and Ray, 1977; Galanopoulou-Sendouca et al., 1980); and these agree with those found in the Turkmen experiments (Bakasov, 1977; Bakasov et al., 1976; Kudratullaev, 1981). Under the more extreme conditions in the northern part of the USA cotton belt these maxima may become 124-148,000 plants/ha (Bilbro, 1972; Verhalen and Williams, 1992). Current field plant populations measured in Turkmenistan on Government and collective
farms are well below these reported plant populations for maximum cotton yields (see Chapter 4 of this thesis).

At low plant populations uniformity of plantings may be important and lower plant populations may be recommended where stands are uniform (Lee, 1968). This is corroborated by the work of Marani et al. (1974) who found that where large plants can be grown in a long season environment, a low plant population may be accepted without lowering yields. However, as established above (Bilbro, 1972; Verhalen and Williams, 1992), for small plants in short season environments higher populations will be needed for optimum yields. It has also been well established that very high or low plant populations reduce lint yields of cotton (Bilbro, 1981; Bridge et al., 1973; Burhan, 1965; Ehlig et al., 1971; Fowler and Ray, 1977; Hawkins and Peacock 1970; Hawkins and Peacock 1971; Hawkins and Peacock 1973; Johnson, 1969; Smith et al., 1979; York, 1983).

In some experiments no yield increases were noted to changes in plant population (Baker, 1976; Bednarz et al., 2000; Buehring and Dobbs, 2000; Buxton et al., 1977; Jones and Wells, 1998; Kerby et al., 1990a; Koli and Morrill, 1976; Rao and Weaver, 1976).

Whilst the wide range of populations found to give high experimental yields may indicate that cotton is very adaptable, the literature indicates that populations of 100,000 plants/ha or more are required under short season conditions. Regardless of environmental conditions, populations that are much higher or lower than the optimum for those conditions may reduce yield.

The fact that optimum plant populations for yields of seed cotton and lint vary from one experiment, season or geographic situation to another is explained by a number of factors which may affect levels of irradiance in the growing canopy (Kittock et al. 1986). These include a
tendency across different locations for optimum plant populations to be greater in short season environments. It may be recommended to plant a cultivar (upland or Pima) with a higher plant population (Kerby et al., 1996) under such conditions.

Levels of irradiance in the growing canopy may also explain an observed interaction between row spacing and plant population found in studies carried out by Maas (1997) which indicate that interplant competition in cotton (which underlies the yield response to plant population) commences shortly after adjacent plants made physical contact within and across the row.

The experiments conducted by Hoskinson et al. (1972) demonstrate a close relationship between effect of row spacing and plant population on cotton yields when plant stands with different row spacings are being investigated at the same densities. In this experiment boll distribution (bolls per plant) was investigated in narrow row cotton systems. In the experiments the effect of doubling plant populations (from 100-200,000) on bolls per plant (2.3-1.2) when row width was constant (25cm) was almost the same as doubling row width (at 50cm, bolls per plant were 2.3-2.5). Doubling row width (25-50 cm) halved plant population but increased bolls/plant from 1.8-3.0. On another soil type doubling row width (25-50 cm) halved plant population but increased bolls/plant from 1.8-3.6.

In experiments conducted by Boquet and Coco (1993) cotton in 75 cm rows yielded higher than 100 cm rows on clay soil (where growth was restricted), but not on silt loam. In this study, rows at 100 cm spacing were planted at 16 seeds per metre but at 75 cm spacing at 12 seeds per metre so that plant population would be the same for each row spacing. Row spacing had no effect on per hectare total vegetative growth or on the distribution of growth (main stems, sympodial and monopodial branches) in this experiment. Therefore it may be hypothesized that solar interception was also the same at both row spacings, and differences in yield in the experiment
may be attributed simply to less competition within rows at the same plant population for the narrower row spacing, rather than for greater light interception at differing row spacings.

The row spacing x plant population interaction may be confounded in experiments where differing row spacings are assigned differing plant populations. For example the experiments conducted by Buehring and Dobbs (2000) where plant population ranging from 132,000 to 265,000 plants/ha were used in 19 cm rows, but plant population of 89,000 to 120,000 plants/ha were used in 75 cm rows.

Other factors such as a genotype associated with plant architecture and optimum levels of late season leaf area index, affect or interact with plant population to determine the extent of the yield response to optimum populations (Heitholt, 1994). Kittock et al. (1986) demonstrated that the optimum plant population for *G. barbadense* (‘Pima’ cotton) was related to final plant height. They suggested that in the San Joaquin Valley, California Pima cotton is more sensitive to low plant population than Acala cottons, presumably due to the light interception qualities of the Pima canopy and a leaf type that allows more light penetration into the canopy (Kittock et al., 1986).

The effect of late planting (Mcinski et al. 1990) can also affect the extent of yield responses to optimum plant population, so that a wide cultivar of these should be expected. This is borne out by the range of responses reported in the literature (and indeed by those experiments listed above in which there is no recorded response). For example the yield advantage of optimum over lowest plant population treatments was reported as 6-7% in Heitholt (1994); 7% in Bruyn et al. (1989); 11.2% in Bridge et al. (1973); 12% in Kumar (1988); 15% in Gannaway et al. (1995); 25% in Fowler and Ray (1977); and 42% in Anastassiou-Lefkopoulou and Sotiriadis (1984).
Several studies report increased LAI with increased plant population (Buxton et al., 1977; Fowler and Ray, 1977; Galanopoulou-Sendouca et al., 1980; Heitholt, 1994; Jones and Wells, 1997; Kerby et al., 1990a). Buxton et al. (1977) also reported that the increase in LAI associated with increased plant populations is exaggerated in the central part of the canopy. The increased LAI associated with high population has been shown to reduce the efficiency of light interception per unit leaf area (Heitholt, 1994). Mean net assimilation rate (NAR) may also decrease with increasing plant population (Bednarz et al., 2000). The altered light environment in the canopy under high plant population was suggested by Constable (1986) to prevent sympodial branches from producing distal fruiting sites. This contention has been adequately proven experimentally (Bednarz et al., 2000; Constable, 1991; Jenkins et al. 1990a).

Fruit production on an individual plant basis (squares, numbers of immature and mature bolls) is inversely related to plant population (Jones and Wells, 1997; Hoskinson et al., 1972; Mass, 1997; Wanjura and Bilbro, 1977). More specifically first fruiting position bolls, the crucial fruiting position in determining cotton plant yields (Bourland et al., 1992a,b; Bourland et al., 1990; Bourland et al., 1991; Heitholt, 1997), decreases with increased plant population (Bednarz et al., 2000). The additional plant numbers in the higher populations, however, result in more first position fruit on an area basis (Bednarz et al., 2000), or in general more flowers and yield on a per area basis (Anastassiou-Lefkopoulou and Sotiriadis, 1984).

A number of studies have found boll size is inversely related to plant populations (Baker, 1976; Bridge et al., 1973; Buxton et al., 1979; Fowler and Ray, 1977; Galanopoulou-Sendouca et al., 1980; Hawkins and Peacock, 1971; Hawkins and Peacock, 1973; Jones and Wells, 1997; Johnson and Walhood, 1972; Rao and Weaver, 1976; Smith et al. 1979). However, Kerby et al. (1990a) and Samra et al. (1985) found no variation in lint/boll at increasing plant populations.
2.9.2 Quantitative response

For a number of species total dry matter increases asymptotically with increasing plant populations (Constable, 1975). Reproductive yields (seeds per unit area) may show a parabolic relationship where yield declines past a critical plant population (Holliday, 1960a,b; Willy and Heath, 1969). Bridge et al. (1973) concurred with Holliday’s (1960b) general proposition for the case of cotton (*G. hirsutum* L.) in that yield response was approximately parabolic.

For cotton Hearn (1972c) used the relationship

\[ W^o = a + b (x_1, x_2)^{-1} \]


to describe yield per plant (*W^o*) in terms of within row (*x_1*) and between row (*x_2*) spacings to describe responses of cotton in Uganda.

Anastassiou-Lefkopoulou and Sotiriadis (1984) studied plant populations from 2.7-17.6 plants/m\(^2\) in 1970-75 in Sindos, Greece and found asymptotic curves fitted the relationship between yield and plant populations better than did parabolic. Plant height, bolls/plant, yield/plant and boll weight were negatively correlated to plant populations in this study while flowers/m\(^2\) and yield/m\(^2\) were positively correlated. The variability of plant yield, expressed by the coefficient of sensitivity, (c.v. as a percentage of yield) was negatively correlated to plant population, indicating that the stability of production increased with an increase in plant population. The greater the number of flowers/plant or per m\(^2\) in this study, the less the boll retention. This effect on boll retention is supported in some studies (Fowler and Ray, 1977) but not in others (Baker, 1976; Fowler and Ray, 1977; Low and McMahon, 1973).
Gutstein (1973) found that the simple and quadratic equations proposed by Holliday (1960a,b) and the simplified exponential reciprocal expression proposed by Bleasdale (1967) adequately described the relationship between yield and plant population over the whole range of densities experimentally tested in Israel of 1-21 plants/m$^2$. Genotype differences were found. The ultimate response type was asymptotic for the *G. hirsutum* cultivars Acala 4-42 and Acala 1517C and parabolic for the other *G. hirsutum* and the two *G. barbadense* cultivars used. Treatments involving late irrigation, which promoted prolific vegetative growth during the reproductive phase, resulted in a change from an asymptotic to a parabolic response pattern. For parabolic responses the optimum plant density was 4-57 plants/m2, whereas for asymptotic responses it tended to infinity or at least was outside the range tested. Estimated maximum yields were 1.94 t/ha for dryland cotton and 4.6 t/ha for irrigated cotton. Gutstein (1973) further concluded that an early artificial growth termination during the growing season in cotton leads in most instances to a parabolic yield response with a finite optimum plant density. On the other hand, a long reproductive period by preferentially raising seed cotton production per plant and per unit area in the higher plant densities (8 plants/m$^2$ and above) generally results in an asymptotic response type. This parabolic yield response was corroborated by Larson *et al.* (1996), using the data of Bridge *et al.* (1973) to validate the COTTAM yield response crop simulation model. The optimum plant population was 142,000 plants/ha predicted by the model, developed for the northern end of the cotton belt in the USA, compared to 131,000 plants/ha in the data reported by Bridge *et al.* (1973) for experiments conducted in Mississippi. Kumar (1988) also records responses in all three experimental seasons and averaged for all seasons as parabolic ($y = 707.75+3.25x-0.0113x^2$, $r^2=0.99$). Johnson and Walhood (1972) using the cultivars Acala SJ-1, Acala cluster and okra leaf variant of Stoneville 7A at densities of 72-507,000 plants/ha presented their data by fitting a quadratic curve to the population means averaged over three locations.
Constable (1997) gives typical asymptotic response as long term results for conventional *G. hirsutum* cultivars in Australia. However, new genetically modified cultivars with low insect attack and ‘tipping out’ may have a more parabolic response curve (J. Marshall, Cotton Seed Distributors, Narrabri, unpublished data 2002; G. Constable, Cotton Research Institute Narrabri, pers. comm. 2003).

In summary, it may be said that a parabolic response in yield to plant population is characteristic of short season cotton growing areas in which conventional cultivars (as opposed to genetically modified cultivars) are grown and that an asymptotic response is characteristic of long season cotton growing areas where conventional cultivars are grown.

### 2.9.3 Specific plant population effects on fruiting bodies and their distribution

Studies have been carried out on field crops like barley and wheat to investigate the dynamics of competition due to plant population within the plant community (Soetono and Puckridge, 1982), but such studies are less common for cotton (Maas, 1997). Studies that have been undertaken show cotton has an amazing ability to compensate for variable spacing (Kerby *et al*., 1996b). Interplant competition in cotton commences shortly after adjacent plants make physical contact within and across the row (Maas, 1997).

Plant population influences both the number of fruiting positions on the cotton plant and the distribution of harvestable bolls (Baker, 1976; Fowler and Ray, 1977; Galanopoulou-Sendouca *et al*., 1980).
TABLE 2.3  Plant population effects on fruiting bodies and their distribution

<table>
<thead>
<tr>
<th>Author</th>
<th>Location</th>
<th>Effect of population on fruiting bodies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buxton et al. (1977)</td>
<td>Phoenix and Summerton, Arizona, USA</td>
<td>Each 5 plants/m² increase in population decreased main stem node by one  Each 8 plants/m² increase in population decreased number of monopodial branches per plant by one  Each 11 plants/m² increase in population raised lowest sympodial branch with a boll by one  Increasing population in the range 7-30 plants/m² reduced percentage of bolls on monopodial branches from 25 to 0</td>
</tr>
<tr>
<td>Kerby et al. (1987a)</td>
<td>Number of cotton growing areas in USA</td>
<td>Proportion of FP1 bolls increased by one for every 2,500 plants/ha in the range 37-136,000 plants/ha</td>
</tr>
<tr>
<td>Kerby et al. (1990b)</td>
<td>Shafter, California, USA</td>
<td>Node of the first fruiting branch (FFB) 6.7 at 50,000 plants/ha compared to 7.2 at 100,000 plants/ha  Average fruiting branch length declined as population increased (36.5-23.5 cm over the range 5-15 plants/m²)</td>
</tr>
<tr>
<td>Jenkins et al. (1990a)</td>
<td>Mississippi, USA</td>
<td>FFB increased by one with a population increase from 110-173,000 plants/ha</td>
</tr>
<tr>
<td>Bednarz et al. (2000)</td>
<td>Tifton, Georgia, USA</td>
<td>Proportion of FP1 fruit increased as population increased</td>
</tr>
</tbody>
</table>

2.9.4  Specific plant population effects on phenological development

Earliness is of paramount importance for the cotton crop throughout the world leading to lower production costs, early land preparation for the next crop, harvesting efficiency, reduce risk of late season pests like Helicoverpa armigera and reduced deterioration of fibre quality in the case of unfavorable conditions during the harvest period (Galanopoulou-Sendouca, 2002). Avoidance of diseases, particularly to Verticillium wilt (Verticillium dahliae), is a further benefit of earliness (Chlichlias and Galanopoulou, 1976).

Rate of appearance of fruiting positions in cotton is an important component of earliness. As early as 1927 McNamara et al. (1927) noted a tendency for plastochrons (time intervals between successive developmental events) to increase with close plant spacing. Kerby and Buxton (1976) hypothesized that it should be possible to shorten the time interval between successive fruiting
positions by combining the accelerated fruiting rate of okra leaf types with high plant density. Kerby and Buxton (1978) evaluated the influence of leaf type (size) and population on the rate of fruiting position appearance along cotton branches and found that plants grown at high densities generally had longer sympodial (number of days between occurrence of successive fruiting positions along a fruiting branch) and monopodial plastochrons (in this case the number of days between FP1 of successive fruiting branches) than plants at low population. Plant environment may also affect plastochrons in cotton. Increasing temperatures from sub-optimal to optimal may increase the rate of appearance of reproductive structures and lower plastochron (Hesketh et al., 1972), as may nitrogen (Gardner and Tucker, 1967; Jones et al., 1974; Thompson et al., 1976).

Munro (1971) and Munro and Farbrother (1969) reported plants at high populations had larger plastochrons (increased time periods between reproductive events) than those of low populations. Population may affect both sympodial and monopodial plastochron (Munro and Farbrother, 1969). Buxton et al. (1977) have also reported that high population reduced the number of main stem nodes in cotton. This is consistent with previous studies showing that increasing population increases monopodial plastochrons.

Saleem and Buxton (1976) found somewhat lower total available carbohydrate levels in leaves of cotton from high plant population cotton than in those grown at lower densities. Thus increased plastochron of plants at high populations may result in part from reduced availability of carbohydrate. Plants at high populations would be expected to exhibit low photosynthetic rate per unit leaf area due to greater mutual shading (Pegelow et al., 1977).

Reported effects of plant population on earliness have also been inconsistent. Mohamad et al. (1982) found that increased populations delayed maturity while Smith et al. (1979) reported the opposite. Literature on the effect of good early season growing on earliness is also inconsistent.
Ashley et al. (1965) reported that early boll set was improved when early season conditions stimulated growth. However, Leigh et al. (1974) reported that good growth due to early irrigation increased canopy attractiveness to insect pests that feed on squares.

Earliness has been reported for narrow row, high plant density (UNR) cotton for many areas in the USA (Ehlig et al., 1971; Hefner, 1971; Andries et al., 1971). Hawkins and Peacock (1968) measured delayed maturity with wide row (i.e. ‘skip row’) cotton. However George (1971) and Niles (1970) did not obtain earliness with narrow rows. In experiments where no report of crop earliness is made but where yield is increased, a yield equivalent to that from wide rows can be harvested at an earlier date (Constable, 1975). The shortened fruiting period of narrow row cotton may have the advantages listed above.

2.9.5 Summary of specific plant population effects on components of cotton yield

In summary, the following specific plant population effects may be discerned.

- Populations of 100,000 plants/ha or more are required for optimum yields of cotton under short season conditions.

- In the literature there is a range of increases in yields reported at optimum plant populations of from 6% to 42%.

- A paraboloic response in yield to plant population is characteristic of short season cotton growing areas in which conventional cultivars (as opposed to genetically modified
cultivars) are grown and an asymptotic response is characteristic of long season cotton growing areas where conventional cultivars are grown.

- Fruit production on a ground area basis is greater in the first sympodial position as population increases, while fruit production on a ground area basis in third positions and monopodial branches is greater as population decreases. Cumulative yield from sympodial branches also increases with density.

- Plants at high populations have larger plastochrons (increased time periods between reproductive events) than those of low populations. Population may affect both sympodial and monopodial plastochron. High populations reduce the number of main stem nodes in cotton. This is consistent with studies showing that increasing population increases monopodial plastochrons.

- Reported effects of plant population on earliness have also been inconsistent.

- It may be hypothesized that when solar interception is the same at two row spacings, differences in yield in these conditions may be attributed to less competition within rows (greater inter-plant distance) at the same plant population for the narrower row spacing.

- Plant density may interact with other factors in affecting components of cotton yield.
2.10 Effect of row spacing on cotton yield

Traditional row spacing for cotton in the cotton belt of the USA is 100 cm (Burch, 1989). In many experiments 75 or 50 cm row spacings have been found to increase yields (Andries et al., 1971; Briggs et al., 1974; Heilman and Namken, 1987; Heilman et al., 1989; Johnson et al., 1974; Kerby et al., 1990a; Peacock et al., 1971). This response may depend on soil texture (Williford et al., 1986; Boquet and Coco, 1993) or result in more fruiting points without consistently improving yields (Constable, 1977a). Advantages to narrow rows correlated well with increased light interception and dry matter production in the experiments reported by Boquet and Coco (1993).

Krieg (1992) suggested increased potential of narrower rows came as a result of increased light interception. It has also been shown in Greek cotton growing areas that the superiority of narrow rows is more evident when the prevailing conditions prohibit canopy closure by mid-July in 100 cm rows in short season environments (Galanopoulou-Sendouca et al., 1980). Greater plant exploitation of solar energy and soil may be due to spatially uniform distribution of plants in narrow rows (Heitholt et al., 1993).

Early plant maturity, limited plant growth and lower first fruiting branch (FFB) were confirmed in narrow row cotton by Heitholt et al. (1993), Robinson (1991) and Williford (1992a). Heilman et al. (1975) found that row configuration did not significantly affect micronaire, strength or length in any of the three years of their experiment.

Differences in yield in row spacing experiments may be simply attributed to less competition within rows at the same plant population for the narrower row spacing, rather than for greater light interception at differing row spacing (Boquet and Coco, 1993). Further experiments by
Boquet and Coco (1996) found optimum plant populations for 75 cm. rows to be 64,000 p/ha and for 100 cm. rows 96,000 p/ha (yields were maximized with 10 plants per meter of row in the 100 cm. rows and 5 plants per meter of row in the 75 cm. rows). Results demonstrated little difference between 75 and 100 cm. rows; and that closer rows require higher N rates and lower plant populations. These results also tend to confirm the view that in some cases yield increases due to narrow rows may be attributed to less competition within rows at the same plant population for the narrower row spacing. ‘Skip-row’ planting system trials may also support this hypothesis. King et al. (1986) conducted a three-year experiment comparing skip-row planting patterns in Alabama, USA. On the actual area planted basis, yields increased 29-62% using skip-row planting patterns, but when yields were calculated on the basis of land used (per ha basis), yields were 12-46% less on skip-row patterns.

2.11 Plant population and row spacing interaction

Factorial experiments by Boquet and Coco (1996) conducted over four years in clay soil examined two row spacings (75, 100 cm), two irrigation regimes (irrigated vs. non irrigated), four plant densities (64,000, 96,000, 128,000 and 161,000 p/ha) and four N rates (67, 101, 135 and 168kg/ha). Row spacing x plant population and row spacing x N interactions were significant, but there was no significant interaction of irrigation with row spacing, irrigation with N rate or irrigation with plant density. Yields in this experiment were maximized with 10 plants/m of row in the 100 cm rows and 5 plants/m in the 75 cm rows. This being consistent with the hypothesis reported above, i.e. differences in yield in the experiment may be attributed simply to less competition within rows at the same plant population for the narrower row spacing, rather than for greater photosynthetic photon flux density or light interception at differing row spacings.
2.12 Interaction between plant population and genotype

Genotypes varying in growth habit may respond differently to increases in plant density (Mohamad et al., 1982). Kerby et al. (1990a,b) report that large vegetative cultivars with low harvest index yield best at low populations, small determinate cultivars with high harvest index perform better at high plant population. These findings agree with those of Kittock et al. (1986), that plant size dictates optimum population. It seems to make no difference whether size is limited by environmental stress, cultivar or growth regulators, small plants have higher optimum plant population than do large plants (Kerby et al., 1996a,b). However, Smith et al. (1979) and Bilbro (1981) have reported that differing cotton genotypes have similar yield responses to plant population

Optimum plant population for differing genotypes may also be different due to this interaction. Gannaway et al. (1995) found that early maturing cultivars gave best yields at high populations while later maturing cultivars gave best yields at relatively low population.

Earlier investigations (Johnson and Walhood, 1972) attributed the genotype x population interaction to differences in the number of non-fruiting plants and the proportion of stem weight relative to total weight in differing cultivars at increased populations; the okra leaf genotype having the highest fruiting efficiency and this parameter decreasing less with increasing population than for non-okra leaf cultivars. More recent work that attempts to explain the effect of plant density and genotype on yield has involved an investigation of these effects on light interception and leaf area index or ‘LAI’ (Heitholt, 1994). These findings indicate that optimal plant density is higher for okra-leaf than for normal-leaf genotypes due to their differing PPFD interception and LAIs and that a maximum LAI of 4.0-5.0 is required to maximize cotton lint yields in this environment (Heitholt, 1994). Cotton genotypes that exhibit rapid development of
LAI have been reported to yield higher than genotypes with slower LAI development (Wells and Meredith, 1986a). Genotypes exhibiting higher early season LAI also exhibited increased light interception and canopy photosynthesis (Wells et al., 1986). Despite the advantages of high LAI during canopy development, LAI during late boll filling was negatively associated with yield in 12 cotton genotypes (Wells and Meredith, 1984b). Lower yielding genotypes partitioned dry matter into excess LAI at the expense of fruit (Wells and Meredith, 1984c).

An understanding of the effect of plant density and genotype on yield should take into account the fact that modern cultivars fruit earlier and are less vegetative than older ones (Wells and Meredith, 1984a; Jenkins et al., 1990a,b).

The plant density x genotype interaction may not be limited to yield. Kerby et al. (1990b) found genotype (reflected in leaf shape) and plant population had no significant effect on seed cotton yields in their study, but the okra leaf genotype was earlier in maturity than the normal leaf genotype.

Management practices, such as using narrow rows (<1m) can also increase light interception during vegetative and early reproductive growth (Peng and Kreig, 1991; Heitholt et al., 1992). Narrow rows may increase yield of cotton leaf types that develop a low LAI such as okra leaf types. The narrow row, okra leaf combination has the potential to increase early season light interception without risking late season high LAI. Heitholt et al. (1992) found that at 10 p/m² an LAI of 3 was necessary to achieve 90% light in 50 cm. rows but an LAI of 4 was required in 100 cm rows. Okra leaf also has the advantage of earlier maturity (Jones, 1982), greater flower production (Wells and Meredith, 1986a; Heitholt, 1993), less boll rot (Jones, 1982) and tolerance to pink bollworm and white fly (Soomro, 1998).
A knowledge of the genotype x plant population interaction has led plant breeders to produce cultivars for new high population/narrow row cotton systems. Andries et al. (1969), Andries et al. (1970) and Melville and Caldwell (1973) postulated okra or ‘super okra’ leaf cotton would be ideal for narrow row cotton. Ray (1970) postulated short plants with short fruiting branches, a minimum of vegetative branches and good light penetration via leaf size, shape and orientation as being suitable for narrow row cultivars. Determinate cultivars produce fruit earlier and more rapidly than standard cultivars in narrow rows (Namken and Heilman, 1973). Niles (1970) and Wilkes (1970) found that cultivars being bred for narrow row culture would give 12-37% increase in yield in narrow over wide rows when the standard cultivar would give no increase in yield. Another desirable morphological character is the open plant canopy, achieved by small erect, lobed leaves, so that light is not prevented from reaching the bottom of the stand where the valuable early bolls are located (Bourland and Oosterhuis, 2001).

Early maturing, more determinate cotton cultivars produce significantly more lint from fruiting positions one and two on sympodial branches and on sympodial branches from main stem nodes 6-8 than do later maturing, less determinate cultivars (Jenkins et al., 1990a). These phenological differences will affect management of new cultivars, including the optimum plant populations under which they must be grown (Jenkins et al., 1990a,b).

2.13 Plant population and plant disease interaction

Minton et al. (1972), working in the USA, found that the percentage of plants with Verticillium wilt declined if plant population was increased, particularly if higher populations were achieved through narrow rows. These results are supported by work in Greece (Galanopoulos and Galanopoulou, 1992). George (1971) noted a yield increase with greater plant population if Verticillium wilt is a problem in the early growth stage.
Because of the nature of the *Verticillium* wilt fungus, particularly its inability to increase saprophytically in soil, it is assumed that inoculum potential per plant decreases proportionately to increasing plant density (Wilhelm *et al.*, 1985).

Continuous threat to the cotton industry in San Joaquin Valley of California by *Verticillium* wilt (*Verticillium alboatrum* Reinke & Berth / *V. dahliae* kleb.) is ultimately traceable to the long practiced monoculture of Acala cottons (Wilhelm *et al.*, 1985). A remedy is seen in genetic diversity of cultivars sown. Rotation with early maturing genetically distinct cultivars that possess wilt resistance and are adaptable to high density plantings (Wilhelm *et al.*, 1985).

### 2.14 Effect of seedling diseases and early insect attack on cotton plant populations

In-furrow fungicides are widely used in conventional tillage systems to reduce seedling mortality caused by fungi (Colyer *et al.*, 1987; Minton, 1986). The insecticide aldicarb (2-methyl-2-methylthiopropanol) is often applied with fungicides to control early season insects and nematodes that affect seedling vigor and diseases (Colyer *et al.*, 1987; Minton, 1986).

Several researchers have improved cotton plant populations in reduced tillage systems with application of in-furrow fungicides, suggesting seedling pathogens were involved in seedling mortality (Colyer and Vernon, 1993). Non-lethal infection of cotton seedlings can also result in stunting, delayed fruiting and reduced yields (Colyer and Vernon, 1993; Batson, 1982; Roncardori *et al.*, 1968). Lethal infections result in lower plant population with the risk of lowered yields (Batson, 1982).
Colyer and Vernon (1993) investigated three tillage practices for cotton: conservation (using gramoxone), mouldboard and conventional; as well as seed treatments involving aldicarb as insecticide, pentachloronitrobenzene, a fungicide specific against Rhizoctonia and the fungicide etridiazole, specific against *Fusarium* spp.. Application of insecticide and fungicide improved plant population only in one year, suggesting factors other than plant pathogens like soil moisture and seed-soil contact were involved in reduced plant population in other years.

Although the seed treatment did not always result in increased plant populations, it did protect seedlings on the basis of decreased disease plant indices (Colyer and Vernon, 1993), as non-lethal infections are known to affect yields (Batson, 1982; Roncardori *et al.*, 1968).

In Turkmenistan there is no current literature on the effects of early insect attack on cotton plant populations. This is due to the perception that there is little insect attack in the desert environment in which cotton is grown in this country and also to the effective use of biological control measures to reduce insect pest numbers for two decades. Following many reports of insecticide poisoning in Central Asia, a major change to biological control of cotton pests was initiated some 20–25 years ago. The main emphasis has been on the production of the egg parasitoid *Trichogramma pintoi*. This parasitic wasp is reared in bio-factories on *Sitotroga*. As back-up, another parastoid, *Habrobracon* is also reared on the wax moth *Galleria*. *Trichogramma* is not considered economic in Turkmenistan and efforts in this country are concentrated entirely on the rearing of *Habrobracon*, where the ability of these wasps to move at rates of 100 metres per day and survive by feeding on nectaries, increases their effectiveness (Matthews, 2001).

*Habrobracon* is produced by rearing a cereal pest, *Ephestia elutella* on wheat. Bowls of wheat are infested with *Ephestia* eggs collected in separate metal containers with cloth on the top and bottom. Honey solution was provided at the top cloth cover. 1000 *Habrobracon* per hectare
(supplied as two glass jars each containing 500) is the recommended rate per application. (Matthews, 2001).

Treatment of early seedling diseases by seed dressing with fungicides is made difficult in Turkmenistan and elsewhere in the CIS by the practice of sowing fuzzy seed. There is currently no information on the effect of seed dressing with fungicides on cotton plant populations in Turkmenistan.

2.15 Plant population effect on cotton fibre quality

2.15.1 Cotton fibre properties and their measurement

Color grade, leaf grade, extraneous matter and to some extent staple length are subjective measures of cotton quality; the cotton industry has long sought more objective measures (Ramey, 1999).

The extent of fibre secondary wall thickening determines fibre fineness, this is measured by the micronaire, which measures the fibres’ resistance to airflow (Benedict et al., 1999). Secondary wall cellulose is considered to be a major contributor to the strength of plant cells (Delmer and Amor, 1995). Bundle fibre strength of cotton fibres is measured by the stelometer reading or with high volume instrumentation, ‘HVI’ (Benedict et al., 1999). A particular cultivar grown in a specific environment will produce fibre of a certain length and secondary wall thickening (Ramey, 1986).
All the changes in spinning technology in the cotton industry have in common the requirement of unique and often improved cotton fibre quality (especially strength) for processing (Deussen, 1994).

**2.15.2 Specific plant population effects on components of cotton fibre quality**

Studies of the effect of plant population on fibre length and strength have generally found either no effect (Baker 1976; Bridge *et al*., 1973; Briggs and Patterson, 1970; Hawkins and Peacock, 1973; Gannaway *et al*., 1995; Johnson and Walhood, 1972), or inconsistent effects (Koli and Morrill, 1976).

Brashears *et al*. (1968) and Briggs and Patterson (1970) found that high plant population increased micronaire (reduced fibre diameter) but Hawkins and Peacock (1973) found no effect of plant population on this characteristic and Koli and Morrill (1976) found the effects varied over seasons. Gannaway *et al*. (1995) and Johnson and Walhood (1972) found micronaire decreased with increasing plant population densities.

Hawkins and Peacock (1973) did find row spacing (rather than plant population densities) affected micronaire, 51 cm and 102 cm rows having higher micronaire than 76 cm rows. El-Zik *et al*. (1971) and Douglas and Andries (1970) also found that row spacing affected micronaire; although this characteristic changed negatively with increased row spacing in the former study compared to positively in the latter. Heilman *et al*. (1975), however, found that row configuration did not significantly affect micronaire, strength or length in any of the three years over which their experiment was conducted.
Fibre strength and uniformity index have also been shown not to be affected by row spacing or plant populations in narrow-row cotton production systems (Briggs and Patterson, 1970; Hawkins and Peacock, 1973; Low and McMahon, 1973; Walhood, 1970).

More recent studies by Jones and Wells (1997, 1998), attempted to associate fibre development patterns with flowering date and plant spacing. These are based on earlier work by Meredith and Bridge (1973), which reported declining values of fibre length, micronaire and fibre strength later in the reproductive period, especially after cutout. Quisenberry and Kohel (1975) likewise reported significant linear relationships between either micronaire, fibre per seed or seeds per boll and accumulated HU during boll development.

In the work of Jones and Wells (1998) for plants at low plant population (2/m²), 33 and 65% respectively of their fibre came from flowers initiated before 88 DAP in 1992 and 1993. Plants at high plant population (12/m²) produced 63 and 88% of their fibre from flowers initiated before 88 DAP in 1992/1993. Because of favorable late season weather, plants grown at 2/m² produced more bolls on vegetative branches and at more distal sympodial positions than did plants at 12/m². Boll weight and micronaire were generally higher for earlier bolls at all positions for 2/m². Later bolls exhibited poorer boll and fibre properties (2.5% and 50% span length, fibre strength, elongation and micronaire) indicating negative effects of reduced heat unit accumulation by later bolls. The data reveals significant delays in maturity at lower populations. Overall, bolls produced from the last two weeks of flowering in each year exhibited inferior boll properties and fibre quality, compared with bolls produced earlier in the season. In 1992, fibre %, 50% SL (‘span length’, the alternate kind of fibrograph measurement to ML, mean length and UHML, upper half mean length, Spinlab, 1998)’, 2.5% SL, strength, micronaire and boll mass were greater in bolls produced during the first 6 wks of flowering compared to the last two weeks Meredith and Bridge (1973) and Verhalen et al. (1975) report similar variations in fibre
properties including a general decline in values as cumulative boll numbers increased and the season progressed. Values for boll and fibre properties reported in Jones and Wells (1998) were all positively correlated with ‘HUBP’ (‘HUBP’ = HU accumulated during boll development of each week of flowers). Micronaire and fibre percentage declined as ‘HUBP’ decreased below 40 heat units per week.

Jones and Wells (1998) suggest that assimilatory factors such as genotype, boll competition, assimilatory capacity, and contrasting light environments (the last three influenced by plant population) are involved in determining boll and fibre properties. An example of assimilatory influence on boll and fibre properties is the increased boll dry weight and micronaire from plants that possessed reduced boll competition induced through flower removal reported in Jones et al. (1996a). Pettigrew (1995) found similar response to altered source-to-sink manipulations in fibre strength and micronaire.

Micronaire was positively correlated with dry boll weight in Jones and Wells (1998), similar results being found in the earlier study of Meredith and Bridge (1973).

To summarize, assimilatory factors such as genotype, boll competition, assimilatory capacity, and contrasting light environments are involved in determining boll and fibre properties. As the last three factors are influenced by plant population, changes in plant populations may affect fibre quality parameters, particularly strength, length and fineness. Any experiments that involve differing cotton plant population treatments should therefore also measure fibre quality.

Where possible, the experiments reported in this thesis also record the effects of plant population on the fibre quality of the cultivars tested.
Other factors that may alone or interacting with plant population affect the yield of cotton are irrigation, fertilizer and plant growth regulators like mepiquat chloride (‘Pix’). The first two are reviewed below; Pix is not used in the CIS.

2.16 Irrigation

Early season water stress may increase flowering in the first two weeks but decrease flowering after three weeks (Kerby et al., 1987a). Early water stress did result in a calculated 10 days earliness in this study (Kerby et al., 1987a). Possible explanation for increased early flowering rates with water stress are that the water stress reduces plant and leaf size so that squares have improved light and temperature (Constable, 1991) and also that water stressed plants are less attractive to early insect pests like Lygus spp. (Leigh et al., 1969).

Lower lint yields due to early water stress were reported by Grimes and Yamada (1982) and Johnson et al. (1989). Guinn (1982a) in a field experiment found that both abscisic acid (ABA) levels and boll abscission rates increased with water stress and decreased as stress was relieved by irrigation. However, Begonia et al. (1986) found that lint, seed and seed cotton yields decreased with water stress period. Decreases in cumulative net number of fruiting forms in stressed plants were attributed mainly to decreased production of fruiting sites as a consequence of water stress rather than an increase in square and flower abscission (Begonia et al., 1986; Kerby et al., 1987a). Lint yields in Mexico were similar for three and four post-planting irrigations and exceeded the treatment with two post-planting irrigations by 58% (Palomo and Godoy, 1998). Vories and Glover (2000) recorded the highest yields from three irrigations. This was despite the fact that this treatment reached NAWF=5 before any other. There was no significant increase from the fourth irrigation before full open boll. Three irrigations yielded about 31% above the no irrigation treatment.
Relatively few studies have investigated interactions between irrigation and plant population. Bruyn et al. (1989) found that no yield response could be measured in a factorial trial with three plant populations, six rates of nitrogen fertilizer and six irrigation regimes. Lack of response suggested by authors as probably due to the beneficial effect of higher water levels being cancelled by leaching of nitrogen (Bruyn et al., 1989). Boquet and Coco (1996) in a factorial trial with two row spacing, two irrigation regimes (irrigated vs. non-irrigated), four plant densities and four nitrogen rates also found no significant interaction of irrigation with row spacing, nitrogen rate or plant density.

2.17 Soil Fertility

Constable (1991) has reviewed data that indicates retention of flowers as harvestable bolls is affected by nitrogen. However, nitrogen levels had only a slight effect on earliness. Cassman et al. (1989) report potassium deficiency as reducing boll numbers of Acala cottons at all fruiting branches but having only a slight effect on maturity.

Begonia et al. (1986) found lint, seed and seed cotton yields increased with increasing rate of nitrogen under dry-land conditions. The increase in yield and yield components were attributed mainly to a greater number of harvestable bolls, although weight per seed, lint weight and number of seeds per boll increased consistently.

Bruyn et al. (1989) recorded an increase in number of bolls/plant and seed cotton per ha with increased nitrogen rates. There was a plant population x nitrogen interaction with 50,000 p/ha in low producing seasons requiring at least 80 kg N/ha for optimum yields while 350,000 p/ha in good seasons needing more than 160kg N/ha for optimum yields. That is, higher populations
have the capacity to respond to higher rates of N. Boquet and Coco (1996) also found a positive and significant row spacing x nitrogen interaction in their experiments. Boquet et al. (1994) found that application of optimal nitrogen rates benefited cotton yield by producing larger bolls at a greater number of fruiting sites. Increase in yield by increase in individual boll weights (IBW) and number of potential fruiting sites (FS) was limited because gains in ‘Horizon 3’ (main stem nodes 17-24) were offset by negative responses in ‘Horizon 1’ (main stem nodes 5-10) when the nitrogen application rate exceeded 84 kg/ha. Gerard and Reeves (1975) also report nitrogen x plant population interactions on earliness and yields in cotton.

2.18 Using crop simulation and plant monitoring in management decisions

A number of crop simulation models have been developed for different areas of the USA (G. Constable, Cotton Research Institute Narrabri, pers. comm. 2003). These models have been used to assist farmers with management decisions as the crop grows. For example, Baker et al. (1983) developed a cotton crop growth model to assist farmers in decision making in South Carolina; Brown et al. (1985) developed ‘COTCROP’ to assist cotton growers in Mississippi; and Stapleton et al. (1973) developed the model ‘COTTON’ for cotton growers in Arizona. In the longer growing season conditions in Australia, similar systems have been developed. However, the criteria for these is that cut-out occurs at NAWF=4 (M. Bange, Leader, Cotton Management Support Systems, Cotton Research Institute Narrabri, pers. comm. 2003).

One difficulty encountered in developing and applying crop simulation models is making comparisons between variables used in the model and parameters that can readily be measured in a field-grown crop (Kerby and Hake, 1996). In many process-based models net carbon assimilation rates and partitioning within the plant are key parameters (Baker et al., 1983; Brown
et al., 1985; Stapleton et al., 1973). The measurement of these parameters in a crop is at best laborious and often not practical (Kerby and Hake, 1996).

Allied to crop simulation models, and developed simultaneously, plant mapping is used for monitoring the growing crop (Kerby and Hake, 1996). Plant mapping and monitoring are based on the assumptions that cotton growers are well acquainted with their fields and that the cotton plant itself can reveal a growth in any one season that may be compared to an established baseline for typical growth (Kerby and Hake, 1996). Kerby and Hake (1996) report that detailed plant mapping for the purpose of crop monitoring has been reported by USDA researchers for many years. In the 1960s fruiting events in the plant were combined into one composite plant diagram to summarize a continuum of plant maps showing development over the crop cycle (Munro and Farbrother, 1969). Plant monitoring allows the various disciplines (agronomy, entomology, plant breeding) to come together in crop management (Bourland and Oosterhuis, 2001).

During the early part of the growing season node number is almost perfectly related to degree-days (‘DD’). From emergence to node 15 a new node is developed every 50 DD. After MSN 15, the rate of nodal development begins to be affected by factors that limit carbohydrate production (plant stresses) or fruit that competes with vegetative growth for available assimilates (Kerby et al., 1987; Kerby and Hake, 1996). Typically 10 FBs have been initiated before this competition begins (Mauney, 1986). Squares on those branches will reach flower at a relatively constant rate of 3 days between FP1s up the main stem (Mauney, 1986). This is a good estimate early in the flowering cycle but values increase beyond three days later in the season (Mauney, 1986; Kerby et al., 1987a).
Plant height as a function of age can be expressed as height to node ratio (‘HNR’) or average inter-node length by dividing plant height by number of main stem nodes, and HNR can be plotted against MSN (Kerby et al., 1992). Early season internodes are close together or HNR <1 up to MSN=8 if plant height is measured in inches (Kerby et al., 1992). Above average temperatures increase the HNR, cool conditions decrease it (Kerby and Hake, 1996). Before 7 nodes, a low HNR does not limit yield potential because leaves have not developed that will support bolls (Kerby et al., 1992; Oosterhuis et al., 1996b). Changes in HNR following MSN=7 become important and determine the ‘carrying capacity’ of the plant because leaves are developing that supply the majority of carbohydrates to developing bolls – this occurs around FB1-12 or about MSN 7-18 (Kerby and Hake, 1996). These fruiting branches or MSN 7-16 will have 70% of the crop yield (Oosterhuis et al., 1996b). HNR may be established for each cultivar and used to establish early season management. For example, a short early fruiting cultivar will have low HNR and will require management that does not limit growth whereas a vigorous full season cultivar with high HNR may require management to control vegetative growth (Kerby and Hake, 1996; Oosterhuis, 1996b). In Arkansas where the COTMAN system of plant monitoring is used, HNR is around 2 for locally adapted cultivars (Oosterhuis, 1996b).

Once bolls begin to compete with vegetative growth the rate on node development slows (Kerby et al., 1987). Fruit growth has a higher priority for carbohydrates than does vegetative growth. ‘Nodes above the white flower’ (NAWF) measures the difference between rate of new node formation and rate at which FP1 flowers move up the plant. Both the initial value of NAWF and the rate at which it declines provide good estimates of the balance between vegetative and reproductive sinks (Kerby et al., 1987a). At first flower, non-stressed Acala plants generally have 8 or 9 NAWF (Kerby et al., 1987a). After early flower, NAWF is a more reliable indicator of the balance in plant growth than the HNR (Kerby and Hake, 1996) and therefore becomes the key parameter in crop monitoring systems like ‘COTMAN’ (Oosterhuis, 1996b).
Physiological cutout occurs when the boll load (sink) consumes all carbohydrate produced by leaves (source) at the time NAWF averages 5.0 for Acala and 3.5 for Pima cultivars (Jackson et al., 1988; Kerby and Hake, 1996). Similarly NAWF can be used to suggest the termination of spraying for late season insects (Bernhardt et al., 1986) and the stage (NAWF=5) when 95% of all FP1 harvestable bolls will have reached the flower stage – sometimes referred to as the number of FBs for the ‘95% zone’ (Kerby and Hake, 1996). The lower productivity of bolls on the bottom side of the ‘95% zone’ may be explained by lower photosynthetic productivity of leaves subtending lower bolls in the crop canopy - this decline in leaf productivity a result of both age and light environment (Oosterhuis and Wullschleger, 1988).

In a study conducted by Kerby et al. (1987) it was found that averaged over all positions, the *G. hirsutum* cultivar Acala SJ-2 retained 29% of all fruiting positions as harvestable bolls and that fruiting positions closest to the main stem (the oldest) have the best chance of survival - FP1 always had the highest probability of having a boll at all MSN positions (Kerby et al., 1987). As the oldest boll on the FB, this gives it some competitive advantage (Kerby and Buxton, 1981). FP1 bolls also have some advantage because they receive substantial supplies from the main stem leaf, their own sub-tending leaf, and leaves further out on the fruiting branch (Horrocks et al., 1978). Data developed in Mississippi (Jenkins et al., 1990a,b) and in Australia (Constable, 1991) agree well with the Californian data presented by Kerby and Hake (1996). Kerby and Ruppenicker (1989) found the largest bolls were produced on FP1 in the middle of the plant (14% larger than on FP2) and that FP2 was larger than FP3 and more distal positions. These results also agree with Jenkins *et al.* (1990a,b) - FP1 14% larger than FP2 - and Constable (1991) - FP1 17% larger than FP2. Fibre quality parameters such as fibre length, micronaire and dye uptake may also be greater at FP1 for middle canopy positions (FB 4-5, 6-8) than for low canopy positions (Jenkins *et al.*, 1990a; Kerby and Ruppenicker, 1989). The importance of the first
fruiting position FP1 is recognized in monitoring systems like ‘COTMAN’ that only use this fruiting position when counting square and boll retention (Oosterhuis, 1996b).

### 2.19 Using plant monitoring in management decisions – the COTMAN system

Crop monitoring provides a precise means to follow a plant’s growth and pinpoint problems for timely actions (Oosterhuis and Bourland, 2001). The crop-monitoring program COTMAN is based on the concept of NAWF being an indicator of cutout and physiological crop maturity (Bourland et al., 1997a,b). COTMAN compares current cotton plant growth with an idealized pattern of cotton crop development to assist farmers with integrated pest management (Bourland et al., 1994; Cochran et al., 1995, Cochran et al., 1998; Holman et al., 1994; Klein et al., 1994a) and agronomic practices (Klein et al., 1994b). COTMAN integrates crop development in any one year with patterns of crop responses to weather built up over several years (Zhang et al., 1994a).

The COTMAN system compares observed development of main-stem ‘squaring nodes’ to a standard target development curve (‘TDC’). Prior to initiation of flowering, ‘squaring nodes is equal to number of sympodial branches and should increase in a linear way to target maximum of 9.25. After flowering, squaring node is equal to NAWF and should linearly decline from a target of 9.25 at 40 DAP to 5 at 80 DAP. The apogee of 9.25 NAWF at first flower was established by dividing 25 (days from square to flower) by 2.7 days vertical flowering interval. A plant should add 9.25 nodes above the first floral bud during the time it takes buds to develop from a square to a flower (Bourland et al., 1997b; Oosterhuis et al., 1996b). The slower nodal development after the first white flower has developed is due to the stress imposed by developing bolls on the plant – the ‘boll load’ (Oosterhuis et al., 1996a). Cutout earlier than the target (80 days after planting in Arkansas conditions) leads to earliness and reduced productivity,
while cutout later than the target results in exposure of the crop to risky late season events such as thunderstorms and insect attack (Bourland et al., 1997b; Zhang et al., 1994a; Zhang et al., 1994b).

The ‘COTMAN’ system, and the assumptions about crop growth therein, particularly the use of ‘NAWF’ and ‘NAWF=5’ to describe the physiological state of the crop and crop maturity, have recently been experimentally verified (Bondada, 1994; Bondada et al., 1996a; Brown et al., 2001; Kharboutli, 2001). However, another question that remains to be answered is how well can COTMAN be applied in short season areas outside the USA. Recent research undertaken in Greece by Kalfountzos et al. (2002) confirms that COTMAN may be used by farmers in short season cotton areas outside the USA, once target development curves have been established for those areas by experimental observations.

The advantage of crop monitoring systems like COTMAN is that they substitute detailed observations of the growing plant and the development of standard patterns of growth or ‘Target Development Curves’ for the equipment needed to measure net carbon assimilation rates and partitioning in some crop modeling systems (Baker et al., 1983; Brown et al., 1985; Stapleton et al., 1973). Where crop monitoring systems accurately describe plant phenology, these systems may also be used to substitute for measurement of light interception in experimental work, as this may be assumed equal in two treatments that show the same phenological development. The measurement of these parameters in a crop is expensive and may also be laborious and often not practical (Kerby and Hake, 1996).
2.20 Conclusions and the scope of this PhD

2.20.1 Conclusions from review

Experiments with Acala cottons under short season conditions have found maximum yields in the range of populations from 86-111000 plants/ha (Kerby et al., 1987a; Baker, 1976; Ehlig et al., 1971; Fowler and Ray, 1977; Galanopoulou-Sendouca et al., 1980); and these agree with those found in the Turkmen experiments (Bakasov, 1977; Bakasov et al., 1976; Kudratullaev, 1981). Current field plant populations measured in Turkmenistan on Government and collective farms are well below these reported plant populations for maximum cotton yields (Chapter 4 of this thesis).

Cotton cultivars have undergone considerable changes worldwide since the 1960s. As genotype affects the cotton plant’s yield response to varying plant populations, optimum plant populations must be estimated for each generation of new cultivars. The need for optimum plant populations to be established for new cultivars is accentuated in countries like Turkmenistan where recent efforts in plant improvement have been to develop cultivars with early maturity. The work reported in Chapter 5 examines yield and fibre quality responses of the ‘new generation’ Turkmen cultivars Turkmenbashi 1 and Iolatan 7 to plant population.

Differences in yield in row spacing experiments may be simply attributed to less competition within rows at the same plant population for the narrower row spacing, rather than for greater photosynthetic photon flux density or light interception at differing row spacings (Boquet and Coco, 1996). This thesis examines this proposition under short season conditions, where the superiority of narrow rows may be more evident when the prevailing conditions prohibit canopy closure by mid-July (Galanopoulou-Sendouca et al., 1980).
The renewed interest in narrow row cotton in Greece (Galanopoulou-Sendouca, 1998) the USA (Weir, 1991) and Australia (Hickman, 2000) indicates that research undertaken on effect of row spacing on cotton yields may have utility outside Turkmenistan and the CIS.

The cotton plant originated from arid areas and exhibits some drought resistance. However, this characteristic is limited in most current commercial cultivars of cotton (Galanopoulou-Sendouca and Oosterhuis, 2003). Investigations on the effect of irrigation frequency on the yield and fibre quality of the cultivars Turkmenbashi 1 and Iolatan 7 are reported in Chapter 7 of this thesis. COTMAN ‘Target Development Curves’ have been used to describe departures from ‘normal’ seasonal conditions like drought (Zhang et al., 1994b). Where there are significant differences in the NAWF measurements made in crop canopies with different levels of water stress, COTMAN ‘Target Development Curves’ or ‘curves’, which are straight line representations of the changes in NAWF in the developing plant with time, may be used to characterize differences in the crop canopies at the different levels.

There was evidence that in the 2002 season in Turkmenistan farmers in many areas of Turkmenistan but particularly in Lebap Velayat were changing from 90 cm to 60 cm rows. This is an indication that farmers in Turkmenistan may have recognized that the increased plant populations necessary for optimum yields may be achieved by planting cotton at the usual inter-plant spacing but at smaller row widths. For this reason; and because interactions between genotype and plant population, row spacing and plant population and irrigation and plant population are all important; the experiments reported in this thesis have been designed to examine these interactions.
2.20.2 The scope of this thesis

Experience in Turkmenistan indicates that the main factors determining seed cotton yields are: quantity of irrigation water applied, largely determined by frequency of application; nitrogen fertilization; sub-soiling or deep ploughing and plant population (Avtonomov and Blijina, 1968; Batekaev et al., 1984; Rejepov et al., 1991; Rejepov et al., 1985; Sergaziev, 1977; TACIS, 1999).

Of these, the first two depend on State inputs and are closely controlled by local authorities. Thus there is no immediate scope for farmer improvement. The third requires cultivation equipment held collectively rather than individually. Hence of the four factors thought to be important, plant population is the only one that individual farmers can control, and is therefore a suitable focus for research and this thesis.

In the Introduction to this thesis, it was noted that there was some evidence that low populations were contributing to the low yields of the region. Chapter 4 reports a survey of plant population on 20 farms in Ahal Velayat, Turkmenistan in 2001, with the aim of evaluating the anecdotal reports of low population.

Subsequent experiments reported in Chapter 5 establish the yield response to population, so that the importance of low field population can be assessed. This work used the new generation of Turkmen cultivars, bred for early maturity, to determine if the response of the new generation of Turkmen cultivars to plant population is the same as the old.
Further experiments sought to explain the low populations found in the field survey, focusing on the effect of fungal seedling diseases, early insect attack and hand thinning on field plant populations of cotton. These are reported in Chapter 6.

The proximity of ARPEC to TACIS headquarters in Ashgabat allowed detailed phenological observations to be made at this site. As target development curves generated by the COTMAN crop monitoring system are particularly responsive to drought (Bourland et al., 1997b) an experiment with irrigation as a main treatment was considered to be an important test of the utility of the COTMAN system in Turkmen conditions. An experiment with irrigation as the only treatment was therefore decided for this site rather than for a plant population x irrigation experiment, similar to the one conducted at CRI and reported in Chapter 5. This is reported in Chapter 7.

The COTMAN curves developed for the first time in Turkmenistan during the 2002 season and reported in this thesis (Chapter 8) have been used to measure the effect of increasing plant population on crop maturity, noted as reduced days after planting to ‘cut-out’ as characterized by NAWF=5. Other curves developed in experiments on the effect of irrigation frequency on cotton yield conducted in Turkmenistan (Chapter 7) will be used to demonstrate the use of the COTMAN system in describing treatment differences in yield when plants are water stressed. The COTMAN curves developed from a row spacing x cultivar x plant population experiment will allow inferences about the amount of light intercepted by a crop canopy to be made by substituting numerous phenological measurements of plants for light measuring equipment that is not available in Turkmenistan. This thesis will therefore use the COTMAN system to explain the effect of factors affecting cotton yields and maturity, rather than using it to simply characterize or describe them. The value of the COTMAN system in describing the potential of
new cotton cultivars for introduction into Turkmenistan and in considering the effects of efforts in that country for breeding for early maturity are described in Chapter 9.

The COTMAN system has been used in experimental work reported in Chapters 5 and 7 of this thesis to see if the treatment differences in yield, maturity and phenology reported can be either summarized, described, or be explained, by hypotheses involving the COTMAN system. An important outcome of this thesis is thus a preliminary assessment of the utility of COTMAN to researchers and plant breeders in Turkmenistan.
3.1 Description of cultivars used

Turkmenbashi 1

Previously called ‘Ahal 1’ this medium staple *Gossypium hirsutum* L. cultivar was produced by the cotton breeders of the Cotton Department of the Agriculture and Water Management Research Institute, Ashgabat, by interspecies crossing of *G. hirsutum* and *G. barbadense* material and selection from the fertile hybrids formed. This cultivar was released in 1998, and in 2001 was planted on 44,000 ha in Turkmenistan.

It is a very early maturing cultivar with 103 days to cutout, 27 days earlier than the standard *G. hirsutum* cultivar (‘133’) bred in Uzbekistan. It ripens well before the first expected frost and its total seed cotton yield is 10% greater than the standard cultivar (133). Fiber GOT is 39% (6.5% higher than standard); fiber yield is 1.7 t/ha under optimum conditions and 0.6t/ha above cultivar 133; fiber length is 35 mm; boll weight is 5.4 g under good conditions; fiber fineness is 6000 on the Soviet scale (‘metric number’); and fiber strength is 4.8 g/cm on the Soviet scale; breaking capacity is 28.8 km. The cultivar is bollworm resistant.

Iolatan 7

*Iolatan 7*, a medium staple *Gossypium hirsutum* L. cultivar, was produced by the cotton breeders of the CRI, Turkmenistan at Iolatan on the basis of repeated selection from the
cross ‘Le-2403’ x ‘October-60’. It was released in 2000 and was planted on 5,000 ha in 2001. This cultivar is earlier than the standard ‘133’, needing 119 days to cutout. It is later maturing by 16 days than Turkmenbashi 1. Average seed cotton yield under optimum conditions is 5.6 t/ha, higher by 370kg/ha than the standard (‘133’). GOT is 36.4%, 3.9% higher than the standard. Fibre length is 37-38 mm, metric number is 6420, fibre strength is 4.6g/cm, breaking capacity is 29.5km. The cultivar is resistant to Verticillium wilt.

9938E

The long staple Gossypium barbadense L. cultivar 9938E was produced by cotton breeders of the CRI, Iolatan on the basis of repeated selection from the line Le-4100. It has not been used commercially in Turkmenistan but is used extensively as a control in State varietal tests. It was released in Tadjikistan and is still grown there. The cultivar is an extremely compact and up-right type and was used in the experiments reported in this thesis for this reason. The cultivar needs 136 days to cutout and is earlier than the standard cultivar ‘F 149’; total seed cotton yield under optimum conditions is 12% greater than the standard or 4.2t/ha; fibre GOT is 36.6% or 3.2% above standard; fibre yield is 1.7t/ha and higher than the standard cultivar F 149; fibre length is 39-40 mm; boll weight is 6.3 g under the best conditions; fibre fineness (metric number) is 7570; fibre strength is 4.8 g/cm; breaking capacity is 36.6 km; 1000 seed weight is 109g; oil content 24.9%. The cultivar is Fusarium wilt resistant.

Iolatan 5

The long staple Gossypium barbadense L. cultivar Iolatan 5 was produced by cotton breeders of the CRI, Iolatan on the basis of repeated selection from the three-way cross of
lines ‘6031’, ‘9453E’ and ‘6118’. The cultivar has been bred specifically for early self-defoliation and starts this by the end of August when planted in mid-April. It was slightly earlier maturing (131 days to cutout) than the control (9871E) in State cultivar trials in 1996-99 and yielded 3.5 t/ha (only 140 kg/ha over control 9871E). It is a tall, somewhat spreading cultivar (110-130 cm) with an ability to avoid white fly (*Bemisia tabaci*) infestation due to its defoliation characteristics (Chapau, 2001).

GOT is 30%; staple length 43-44 mm; strength 4.6 g/cm; breaking capacity 38.6 km; fibre fineness (metric number) is 8430; boll weight under optimum conditions 3.7 g; 1000 seed weight 133 g; defoliation by 1<sup>st</sup> October 96% compared to the standard (9871E) of 46%.

*Ashgabat 97*

The long staple *Gossypium barbadense* L. cultivar Ashgabat 97 was produced by cotton breeders of the CRI, Iolatan on the basis of repeated selection from the cultivar Ashgabat 25, which was released in 1977. Ashgabat 25 was very popular both in Turkmenistan and the CIS. In 1983 it occupied almost the whole area of cotton plantings in Turkmenistan and 51% of the area of long staple plantings for the whole CIS (Chapau *et al*., 1990). However, it is late maturing: 150-155 days to harvest (Chapau *et al*., 1990). Ashgabat 25 was produced by crossing the Egyptian long staple 10964 with the Peruvian long staple 01277 and exposing the hybrid to a selected day-length regime. Suitable progeny were then crossed with the long staple cultivars ‘2525’, ‘8981E’ and ‘9123E’ until the required characteristics were selected by re-combinations from the final cross. Ashgabat 25 represents a success of plant breeders at transforming the original indeterminate plant type of Egyptian long staple cottons to a more compact, early maturing type.
Ashgabat 97 is intermediate in habit between compact cultivars like 9938E and the tall, spreading Iolatan 5. Fiber length is 40-41 mm; fibre strength is 4.9 g/cm; fibre fineness (metrical number) 8120; GOT 34% (4% above 8763E); breaking capacity 39.8 km.

3.2 Data handling

All experiments were analyzed by the Chief Biometrician at the National Institute of Agricultural Botany, Cambridge (NIAB) Dr. John Law, using ‘Genstat’ software.

For the row spacing x cultivar x plant population experiment a covariate analysis was carried out with environmental salting effect on plant growth as the covariate. Results obtained with and without using salting as a covariate were the same (see Chapter 7). This was probably because the major salting damage was confined to one replicate block.
### 3.3 Environmental details

*Climate*

Long term climate data for CRI, Iolatan and ARPEC, Anau are given in Tables 3.1 and 3.2.

**Table 3.1.** Long-term average climate data for CRI, Iolatan

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<th>Daily mean temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Wind speed (m/s)</th>
<th>Sunshine (h/d)</th>
<th>Solar radiation (MJ/m²/d)</th>
<th>Pan evaporation (mm/month)</th>
<th>Precipitation (mm)</th>
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Table 3.2. Long-term average climate data for ARPEC

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<tr>
<td>Feb</td>
<td>4.2</td>
<td>72</td>
<td>1.8</td>
<td>4.3</td>
<td>10</td>
<td>33</td>
<td>28</td>
</tr>
<tr>
<td>Mar</td>
<td>9.3</td>
<td>68</td>
<td>2.1</td>
<td>4.7</td>
<td>13</td>
<td>63</td>
<td>45</td>
</tr>
<tr>
<td>Apr</td>
<td>16.7</td>
<td>58</td>
<td>2</td>
<td>6.5</td>
<td>18</td>
<td>107</td>
<td>47</td>
</tr>
<tr>
<td>May</td>
<td>23.1</td>
<td>46</td>
<td>2.1</td>
<td>9.1</td>
<td>23</td>
<td>170</td>
<td>31</td>
</tr>
<tr>
<td>Jun</td>
<td>28.0</td>
<td>36</td>
<td>2.2</td>
<td>11</td>
<td>26</td>
<td>212</td>
<td>5</td>
</tr>
<tr>
<td>Jul</td>
<td>30.7</td>
<td>33</td>
<td>2.1</td>
<td>11.5</td>
<td>27</td>
<td>231</td>
<td>1</td>
</tr>
<tr>
<td>Aug</td>
<td>28.8</td>
<td>32</td>
<td>1.9</td>
<td>11.4</td>
<td>25</td>
<td>202</td>
<td>1</td>
</tr>
<tr>
<td>Sep</td>
<td>23.4</td>
<td>38</td>
<td>1.8</td>
<td>9.8</td>
<td>20</td>
<td>140</td>
<td>5</td>
</tr>
<tr>
<td>Oct</td>
<td>15.9</td>
<td>53</td>
<td>1.6</td>
<td>7.5</td>
<td>14</td>
<td>78</td>
<td>11</td>
</tr>
<tr>
<td>Nov</td>
<td>8.8</td>
<td>66</td>
<td>1.5</td>
<td>5.3</td>
<td>9</td>
<td>37</td>
<td>27</td>
</tr>
<tr>
<td>Dec</td>
<td>3.8</td>
<td>78</td>
<td>1.5</td>
<td>3.5</td>
<td>7</td>
<td>21</td>
<td>22</td>
</tr>
</tbody>
</table>

At ARPEC, the 2002 season in which all experiments were performed was similar to the long-term average in terms of cumulative heat units (Table 3.3). As outlined in Section 2.6, cumulative heat units required from planting to seedling emergence are 80 HU; emergence to first square 425 HU and planting to first flower 777 HU (Constable and Shaw, 1988). For the experimental season at Ashgabat, these milestones were achieved on or around the second day of May in the experimental year (compared to the last day of April in an ‘average’ year); the fourth day of June in the experimental year (compared to the last day of May) and the 27th June in the experimental year (compared to 22nd June). As rain did not delay planting at this site development of experimental fields could be described as late to ‘normal’ on the basis of dates of developmental milestones in the experimental and the
average year. At Ashgabat/Anau 2150 HU were recorded for the experimental crop growing season compared to 2173 HU during the same growing period for an ‘average’ year.

Ashgabat/Anau and other areas in Turkmenistan (crop in the field around 150-155 days) would be regarded as ‘short-season’ by Australian standards (crop in the field 180-190 days) and comparable to areas like Arkansas in the USA and Greece in Europe (Professor S. Galanopolou-Seneca, pers. comm., 2002).

Table 3.3 Long term average and 2002 weather data and cumulative heat units for ARPEC, Turkmenistan

<table>
<thead>
<tr>
<th>Month</th>
<th>Av max</th>
<th>Av min</th>
<th>Av cum HU</th>
<th>2002 max</th>
<th>2002 min</th>
<th>2002 cum HU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr</td>
<td>22.9</td>
<td>11.0</td>
<td>82</td>
<td>21.3</td>
<td>12.0</td>
<td>74</td>
</tr>
<tr>
<td>May</td>
<td>30.0</td>
<td>16.3</td>
<td>428</td>
<td>26.8</td>
<td>15.8</td>
<td>365</td>
</tr>
<tr>
<td>June</td>
<td>35.2</td>
<td>20.5</td>
<td>903</td>
<td>34.6</td>
<td>20.6</td>
<td>833</td>
</tr>
<tr>
<td>July</td>
<td>37.8</td>
<td>23.0</td>
<td>1474</td>
<td>37.6</td>
<td>22.8</td>
<td>1397</td>
</tr>
<tr>
<td>Aug</td>
<td>36.6</td>
<td>20.6</td>
<td>1988</td>
<td>37.1</td>
<td>22.0</td>
<td>1940</td>
</tr>
<tr>
<td>Sept</td>
<td>31.5</td>
<td>15.6</td>
<td>2173</td>
<td>33.9</td>
<td>16.3</td>
<td>2150</td>
</tr>
</tbody>
</table>

Rainfall at Ashgabat/Anau was higher in April (planting month) in 2002 than the long-term average (85.1mm c.f. 47mm). Rain on the 12th and 13th of April (19mm, 7mm) and the 21st and 22nd April (12mm, 17mm) delayed plantings in most parts of Ahal Velayat although experimental plantings at ARPEC, Anau were not delayed, as the plantings were by hand rather than tractor. Falls of 10 mm (26/4/2002), 10 mm (5/5/2002) and 18 mm (8/5/2002) led to soil crusting in many fields in Ahal Velayat, which led to re-planting in many places. Emergence was not till mid or late May in many instances, affecting crop development and reducing yield in much of Turkmenistan, to just over one tonne seed cotton per hectare (Turkmenistan Times, 2002).
Table 3.4  Long-term average and 2002 weather data and cumulative heat units for CRI, Turkmenistan

<table>
<thead>
<tr>
<th>Month</th>
<th>Av max</th>
<th>Av min</th>
<th>Av cum HU</th>
<th>2002 max</th>
<th>2002 min</th>
<th>2002 cum HU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr</td>
<td>24.3</td>
<td>10.2</td>
<td>37</td>
<td>21.9</td>
<td>11.4</td>
<td>74</td>
</tr>
<tr>
<td>May</td>
<td>30.8</td>
<td>14.4</td>
<td>366</td>
<td>29.6</td>
<td>14.8</td>
<td>396</td>
</tr>
<tr>
<td>June</td>
<td>35.2</td>
<td>17.2</td>
<td>792</td>
<td>35.3</td>
<td>18.5</td>
<td>843</td>
</tr>
<tr>
<td>July</td>
<td>37.0</td>
<td>18.7</td>
<td>1283</td>
<td>36.3</td>
<td>18.5</td>
<td>1321</td>
</tr>
<tr>
<td>Aug</td>
<td>34.9</td>
<td>15.7</td>
<td>1695</td>
<td>36.8</td>
<td>17.2</td>
<td>1787</td>
</tr>
<tr>
<td>Sept</td>
<td>30.4</td>
<td>10.8</td>
<td>1953</td>
<td>32.6</td>
<td>10.3</td>
<td>2102</td>
</tr>
<tr>
<td>Oct</td>
<td>24.3</td>
<td>6.2</td>
<td>1992</td>
<td>32.6</td>
<td>11.2</td>
<td>2227</td>
</tr>
</tbody>
</table>

At CRI Iolatan, the 2002 season had somewhat greater cumulative heat units for experimental crops than the long-term average (2227 c.f. 1992 HU, see Table 3.4). This difference is largely due to the long term average monthly maximum and minimum temperatures for October being calculated for the full month, with temperatures declining sharply in the second half of the month; compared to the 2002 season in which temperatures were only recorded for the first 12 days of the month, in which high temperatures still prevailed. For the experimental season at CRI Iolatan these milestones were achieved on or around 1<sup>st</sup> May in the experimental year (compared to 28<sup>th</sup> April in an ‘average’ year with planting date in the middle of April); 2<sup>nd</sup> June in the experimental year (compared to the last day of May) and the 26<sup>th</sup> June in the experimental year (compared to 25<sup>th</sup> June). CRI, Iolatan would be characterized as ‘short-season’ in terms of HU as in the case of Ashgabat/Anau above.

Rainfall in April, although almost the same as the long-term average, delayed planting (done by tractor at this site rather than by hand at ARPEC, Anau) till the 24<sup>th</sup> April due to a heavy fall on the 14<sup>th</sup>.
Soils

Soil type at both ARPEC, Anau and CRI Iolatan are described as sandy silt loams (Russian Soil Classification System). A soil test of the experimental site at ARPEC, Anau conducted by the Turkmen Agricultural University on 30/5/2002 showed pH 7.3; Colwell bicarbonate P, 22.3 mg/kg; K, 2.41 mequivalent/100g; nitrate-N, 12.5 mg/kg; organic matter, 0.69%; and total N, 0.15%. Total alkalinity was 0.027; chloride, 0.005 mg/kg; sulphate-sulphur, 0.041 mg/kg; Ca, 0.017 mg/kg; Mg, 0.022 mg/kg; and Na, 0.02 mg/kg. This was a typical cotton soil in structure and chemistry, with sufficient K but needing P, S and N fertilizer (Professor B. Mammedkhanov, Soils Department, Turkmen Agricultural University, pers. comm. 2002). No soil test was conducted at CRI Iolatan but the soils in experimental fields there were described as of good structure and fertility by staff of the Cotton Research Institute (S. Kurbangeldiev, Director, CRI, Iolatan pers. comm. 2002).

3.4 Field experiments 2002

Field experiments during 2002 were located at the Ahal Research and Production Experimental Center (ARPEC) at Anau in Ahal Velayat and at the Cotton Research Institute (CRI) Iolatan in Mary Velayat. The following experiments were carried out at ARPEC:

- Plant density x gaps in rows
- Number of irrigations
- Row spacing x cultivar x plant population
- Effect of various seed treatments on early seedling death or ‘early seedling death’
- Effect of kind of hoe in achieving a certain plant population
- Effect of operator on plant density
For all trials conducted at ARPEC there were many agronomic practices in common. Details of the experimental design of each trial and any individual departures from the practices listed below are given in subsequent chapters that discuss these trials in more detail. Common practices in the trials at ARPEC included the following.

Site preparation

The experimental site was prepared by two cultivations in January 2002 followed by deep plowing using Soviet equipment to 40 cm in the first week of February. A survey was conducted 14/2/02 and the field leveled accordingly on 27/2/02. A further survey was conducted 13/03/02 to check the slope was adequate for efficient irrigation. Two further cultivations were made after this and the land furrowed for pre-planting irrigation on 19/03/02.

Planting

Seed of 96% germination was acid de-linted for all experiments by hand and dressed with the fungicide / insecticide compound Rapcol (except for the early seedling death trial, the seed of which was not treated) at 15 g/kg, 10 ml/kg binder and 7 g/kg absorbent. Planting for all experiments took place between 17/04/02 and 20/04/02 after a pre-plant irrigation on 01/04/02.

Fertilizer

Fertilizer applied for all experiments was 18 kg/ha P as superphosphate incorporated pre-planting and before pre-plant irrigation, and 200 kg/ha N as ammonium nitrate.
al., 1985) as one banded application 10 cm from the plant row applied by hand after germination and thinning (5-6/6/02).

Irrigation

After pre-planting irrigation, five further furrow irrigations were carried out for all experiments except the ‘number of irrigation experiment’; on 6/6/02, 6/7/02, 20/7/02, 7/8/02 and 24/8/02. Timing of irrigation was based on the FAO ‘CROPWAT’ computer program (FAO, 1988) using meteorological data for Anau. Each irrigation wetted plots up to the plant line, approximately 1 ML/ha per irrigation.

Weed control

Hand weeding of all plots was conducted 30/4/02 - 3/5/02, 21-24/5/02 and 14-17/6/02. Shielded spraying with Glyphosate (350 mg l⁻¹) was carried out using a knapsack spray on 21/6/02, 25-28/6/02, 4/7/02 and 15-17/7/02.

Observations of phenology

Where phenological observations were made, 10 plants from the middle row of each plot were marked using cotton cloths ‘tied to the first and last of the ten plants’ on 14/6/02 and phenological progress of each plant was recorded using the COTMAN system from 3/7/02 to 7/8/02 for the plant density x gap experiment; number of irrigations experiment and row spacing x cultivar x plant population experiment. On 3/7/02 not all plants had flowered – only those that had were recorded for NAWF. Observations on 3/7/02 were used as ‘first
fruition (FFN) position. Numbers of open bolls were counted 22/8/02, 2/9/02 and 9/9/02 and mature plant heights measured on 15/8/02.

**Harvest**

For the row spacing x cultivar x plant population experiment, hand harvest was conducted 20/9/02 (Rep 1) 23/9/02 (Rep 2) 24/9/02 (Rep 3) and 25/9/02 (Rep 4). For the plant density x gap experiment harvest was conducted 16/9/02 and for the number of irrigations experiment on 16/9/02. Open and green bolls from the 10 marked plants in each middle row were counted at the same time and a 50-boll sample taken at random (top, middle and bottom of canopy in sequence) from the 10 marked plants for all experiments. Seed cotton yields from all plots were then calculated. All collected 50 boll samples were ginned on 2-3/10/02 using a laboratory saw gin manufactured in Tashkent located at ARPEC. Ginned seed was weighed 11/10/02 and fibre in each sample calculated by deduction. GOT and fibre yields per plot were then calculated. Fibre samples were analyzed for length, uniformity, strength and micronaire using equipment provided by the European Union’s ‘Support to the Cotton Sector Project’ at CRI Iolatan. Analyses were conducted by Professor U. Kechagia, Director of the Fiber Institute, Greece.

The following experiments were carried out at CRI:

- Plant density x gaps in rows experiment
- Plant density x number of irrigations experiment

Details of experimental design of each trial and any individual departures from the practices listed below are given in subsequent chapters that discuss these trials in more detail. Common practices in the trials at CRI included the following.
Site preparation

The experimental site was prepared by two cultivations in January 2002. The site had been deep plowing using Soviet equipment to 40 cm in 2001. Two further cultivations were made after this and the land furrowed for pre-planting irrigation on 19/03/02.

Sowing

Sowing by tractor drawn planter with fuzzy seed of 95% germination dressed with the fungicide / insecticide compound Rapcol at 15 g/kg, 10 ml/kg binder and 7 g/kg absorbent at 300,000 plants/ha took place 25/04/02 after a pre-plant irrigation on 8-9/04/02. Plantings were thinned on 15-16/5/02 to give desired plant populations and 50 cm gaps introduced according to treatments on 17-18/5/02. Plant populations were measured on 4-5/6/02 and a few plots adjusted to required plant populations by thinning 13-14/6/02.

Fertilizer

Fertilizer applied was 18kg/ha P as super phosphate incorporated pre-planting and before pre-plant irrigation. 100 kg/ha N as ammonium nitrate (rather than the 200 kg/ha recommended by Regipov et al., 1985) was used on the advice of the breeder of the cultivar used (due to its late maturity and somewhat open canopy). One banded application 10 cm from the plant row was applied by hand after germination and thinning on 5/6/02.

Irrigation

After pre-planting irrigation, five further furrow irrigations were carried out 13/6/02, 3/7/02, 26/7/02, 15/8/02 and 1/9/02. Timings were based on the FAO ‘CROPWAT’ computer
program (FAO, 1988) using meteorological data from the CRI station. Each irrigation
wetted plots up to the plant line – approximately 1 ML/ha per irrigation. There were
difficulties in preventing water movement between plots in the population x irrigation
experiment at this site, due to the site’s location on a field at some distance from the institute
and the CRI itself being some 500 km from the capital, Ashgabat.

Weed control

Hand weeding of all plots was conducted 2/5/02 - 5/5/02, 7-9/5/02 and 15-18/5/02. Weed
control in the experimental area was generally good, requiring no Gramoxone application.

Phenological observations

Due to the difficulty in accessing this site (500 km from the capital, Ashgabat) the author
did not make any phenological observations at this site. For the plant density x number of
irrigations experiment, 10 plants from either of the middle rows of each plot were marked
using cotton cloths at the first and last position on 14/6/02 and a small number of
observations made by two plant breeders of the CRI, Iolatan of phenological progress of
each plant. These values were used to compute phenological progress of treatments in this
experiment. The plant breeders at CRI (but not at ARPEC) were inexperienced in this
system, although their knowledge of the flowering pattern of the cotton plant was excellent
and they received assistance in the field and training in the COTMAN system from
Professor Galanopoulou-Sendouca, who was very experienced in the use of COTMAN.
At harvest, open and green bolls from the ten marked plants in each middle row were counted at the same time and a 50-boll sample taken at random (top, middle and bottom of canopy in sequence) from the 10 marked plants. Seed cotton yields from all plots were then calculated. No collected 50 boll samples could be ginned due to limited access to ginning equipment at this site, therefore GOT and fiber yields per plot could not be calculated at this site nor could fiber samples be analyzed for length, uniformity, strength and micronaire.
4.1 Introduction

Experience in Turkmenistan indicates that the main factors determining seed cotton yields are the quantity of irrigation water applied, nitrogen fertilization, sub-soiling or deep ploughing and plant population (Professor O. Regipov, Head of Irrigation Department, Land and Water Institute, Ashgabat, pers. comm. 2002). Of these, the first two depend on State inputs and are closely controlled by local authorities.

Reports of low populations in commercial cotton crops, made to scientists of the TACIS ‘Support to the Cotton Sector Project’, were supported by measurements of low population in seed production fields during early June 2001 at the two Government farms on which the TACIS Project was located (TACIS, 2001). Mean populations were recorded of 35,700 and 58,200 plants/ha for the medium staple cultivar ‘Ahal 1’ at APREC and 59,800 and 54,700 plants/ha for the long staple cultivars ‘Iolatan 5’ and 9964E at CRI.

The findings indicated that increasing plant populations could improve seed-cotton yields on the Government farms in which the TACIS Project was involved, and that low populations on these farms may have been indicative of a wider industry problem.

A search of available local and overseas literature was made to establish what optimum plant populations would be for the cultivars used.

Kerby et al. (1987a), from a wide range of experiments in California, and international experience reported by Baker (1976); Ehlig et al. (1971); Fowler and Ray (1977) and
Galanopoulou-Sendouca *et al.* (1980), point to optimum cotton yields at 86-111,000 plants/ha population. However, there is a tendency for optimum plant populations to be greater under conditions of severe stress or in ‘short- season’ environments (Kerby *et al.*, 1996). Under the more extreme conditions in the northern part of the USA cotton belt (for example the Texas High Plains) this may become 124-148,000 plants/ha (Bilbro, 1972; Verhalen and Williams, 1992). Where plant growth is limited (as it is in Turkmenistan, see Chapter 3) it may be recommended to plant a cultivar with a higher plant population and under very short season conditions densities as high as 200,000 p/ha may be justified (Kerby *et al.*, 1996). It should be appreciated, however, that such studies are invariably under controlled experimental conditions in which every effort is usually made to eliminate nutritional, water and other constraints to yield.

In Turkmenistan, studies over many years have indicated that plant populations of 100-110,000 plants/ha give maximum yields, although this may increase to 180,000 plants/ha for long staple cultivars under certain conditions (Fursov, 1961; Bakasov, 1977; Kudratullaev, 1981; Kudratullaev *et al.*, 1981; Kurbangeldiev, 1985; Kudratullaev, 1981).

Thus plant populations found at the two Government farms on which the TACIS Project was located were one-half or less than those found to be optimum in studies previously conducted in Turkmenistan and overseas.

Given the importance of population as a determinant of yield, and that reported populations on farms are low, it was decided to survey farm fields to rigorously investigate populations on farms. Twenty farmer’s fields in Ahal Velayat (the district surrounding ARPEC) and twenty in Mary Velayat (the district surrounding CRI) Turkmenistan were selected for survey in August 2001 to obtain estimates of plant population, as well as boll numbers per
plant and boll weight and to compare these with those found on the Government farms measured in June 2001.

4.2 Methods

The cotton field yield-sampling method used was developed by Kurbangeldiev (1985) in Turkmenistan. It involves counting the number of plants in a 10-meter length of row; counting all bolls on 10 plants in this part of the row, and then calculating the average boll weight of a 50 boll sample taken at random from this part of the row to estimate field yields of seed cotton. Twenty samples in each field are taken at random by walking in a ‘W’ path across the whole field. If the row spacing is known (90cm for much of the country) the plant population per hectare can be calculated. This method represents a compromise between accuracy and the practicalities of sampling in fields where hand harvest has in some cases already commenced. Plant heights of each of 10 plants in each of the 20 positions were also recorded.

Initially it was intended that 20 farmer’s fields would be sampled for plant population and yield of seed cotton in both Ahal and Mary Velayats. Political trouble on the Afghan frontier, close to CRI Iolatan, prevented sampling in that Velayat so that only 20 farmers fields in Ahal Velayat were sampled.

Farms in Turkmenistan remain in the early stages of privatization, with lease-holders, who are members of collective farms, initially receiving two-year leases for two or three hectares which may be extended. These are the ‘farmer’s fields’ which were sampled. Four ‘private’ farmer’s fields in each of five collective farms or ‘Daykhan Birleshiks’ in Ahal Velayat –
Nine Commisars (21-24/8/01), Maktamaguli (28-31/8/01), Bugdayli (4-7/9/01), Gayvers (11-14/9/01) and Sopiev (18-24/9/01), were sampled in the periods in parentheses.

The following data were collected for each of the 20 fields sampled: name of field; location; name of collective farm; area of field; cultivar planted and seeding rate; whether germination tests were carried out and results; fertilizer added, type and timing; number of irrigations and timing; and cultivation methods.

All Daykhan Birleshiks and therefore the farmers within them, fall under the control of district (Velayat) administration, which determines the crop agronomy to be used and allocates subsidized inputs of seed, fertilizer, machinery and water. As all the collectives and farmers fields were under state control as far as crop management is concerned, details of fertilizer use, irrigation regime, weed control, insect control and cultivation were given as the same by all farmers interviewed. It could not be determined if the answers given by respondents reflected actual management of fields or the state ‘norms’ (non-complying farmers are penalized).

All farmers responded that they had applied 400 kg/ha of ammonium nitrate in two dressings (one pre-plant, one at first flower) and incorporated 200 kg/ha superphosphate before planting. All provided five irrigations for the season according to the State norms of 1 ML/ha for each irrigation. Irrigation timings were also according to State norms (pre-planting followed by planting and hilling-up into 90 cm rows; at appearance of main-stem node 5-6; at appearance of first pin-head square; at flowering and during boll filling). Fields were sown with 100 kg/ha fuzzy seed testing 90% or above in state tests and this was thinned and weeded by hand at the end of April using Turkmen-style hoes. Further inter-row cultivation was by tractor-drawn implements (tynes or rotavator).
Plant population and yield of seed cotton per hectare were calculated for each field.

Following statistical analysis of all 20 fields, the correlations (r) between plant population and number of bolls/plant, boll weight, bolls/ha and seedcotton yields for the five highest and five lowest fields were compared in order to see to what extent plant populations could be increased in high and low yielding fields without producing evidence of individual plant stress as measured by the number of bolls per plant and the weight of individual bolls on each plant. It was assumed that mean yield was an indication of the degree of constraint the crops were grown under.

4.3 Results and Discussion

Summary statistics for the results are given in Table 4.1. Mean population was 45,219, but population was highly variable, ranging from 20-60,000 plants/ha. Over all 20 fields, yield was weakly although significantly (P<0.05) positively related to plant population (r = 0.25). The mean population was less then half of the lower end of the range of optimum populations found in research studies in Turkmenistan (Fursov, 1961; Bakasov, 1977; Kudratullaev, 1981; Kudratullaev et. al., 1981; Kurbangeldiev, 1985; Kudratullaev, 1981).

Mean yield was 2,065 kg/ha seed cotton, which is close to the mean yield (2,170 kg/ha) reported for 36 randomly chosen fields spread across the five CIS States of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan surveyed by the TACIS ‘WARMAP’\(^1\) project in 1996 (TACIS, 1999).

\(^{1}\) Water Resources Management and Agricultural Production in the Central Asian Republics
<table>
<thead>
<tr>
<th>Plant population (plants/ha)</th>
<th>Sensitivity coefficient of plants/10 m row (^1)</th>
<th>Bolls/plant</th>
<th>Boll weight (g)</th>
<th>Bolls/ha</th>
<th>Yield of seed cotton (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of 20 fields ± (s.d.)</td>
<td>45,219 (12,358)</td>
<td>29.9% (13.4)</td>
<td>11.1 (4.6)</td>
<td>4.29 (0.48)</td>
<td>478,219 (185,729)</td>
</tr>
<tr>
<td>Range</td>
<td>20,000 – 59,833</td>
<td>13.6-62.8%</td>
<td>5.6- 20.7</td>
<td>3.65-4.89</td>
<td>280,873– 916,800</td>
</tr>
</tbody>
</table>

Correlation coefficient (r) with PP and its significance (*P<0.05)

\[^1\text{calculated as s.d. of average of plants/10 row divided by the average expressed as a percentage. The component ‘plants/10 m row’ was the average of 20 samples in each of the 20 sampled fields (400 samples)}\]

In Table 4.1 the component ‘plant population’ was the average of 20 samples in each of the 20 sampled fields (400 samples). The standard deviation of this component was the mean standard deviation of plant population within each of the 20 sampled fields. The variability of plant occurrence over all 20 fields was calculated as the standard deviation for plants/10 m row within each field divided by the number of plants/10 m row, expressed as a percentage (sensitivity coefficient). The correlations between the sensitivity coefficient and plant populations over all fields was also calculated (‘r’). Sensitivity coefficient was 29.9% measured over 20 fields and the correlation coefficient for the relationship between coefficient of sensitivity and plant population was r = -0.53 (P<0.05).

For further analysis, the relationship between population and yield, and its components, was studied for the five fields with the lowest seed cotton yield (Table 4.2) and the five fields with highest yields (Table 4.3). This was done to determine the extent to which plant population may be a factor determining cotton yields when management factors like soil-preparation, water and nutrients are in poor supply and when they are adequate.
Table 4.2  Plant population, plants/10-m row, bolls per plant, bolls per ha, boll weight and yield for the five lowest yielding fields surveyed, Ahal Velayat 2001

<table>
<thead>
<tr>
<th>Plant population (plants/ha)</th>
<th>Sensitivity coefficient of plants/10 m row(^1)</th>
<th>Bolls/plant</th>
<th>Boll weight (g)</th>
<th>Bolls/ha</th>
<th>Yield of seed cotton (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of 5 fields ± (s.d.)</td>
<td>38,444 (11,634)</td>
<td>32.8% (7.8%)</td>
<td>8.2</td>
<td>4.09</td>
<td>291,454 (30,299)</td>
</tr>
<tr>
<td>Correlation coefficient (r) with PP and its significance (*P&lt;0.05)</td>
<td>-0.40(^*)</td>
<td>-1.00(^*)</td>
<td>-0.90(^*)</td>
<td>0.62(^*)</td>
<td>-0.59(^*)</td>
</tr>
</tbody>
</table>

\(^1\) calculated as s.d. of average of plants/10 row divided by the average expressed as a percentage. The component ‘plants/10 m row’ was the average of 20 samples in each of the 20 sampled fields (400 samples).

Table 4.3  Plant population, plants/10-m row, bolls per plant, bolls per ha, boll weight and yield for five highest yielding fields surveyed, Ahal Velayat 2001

<table>
<thead>
<tr>
<th>Plant population (plants/ha)</th>
<th>Sensitivity coefficient of plants/10 m row(^1)</th>
<th>Bolls/plant</th>
<th>Boll weight (g)</th>
<th>Bolls/ha</th>
<th>Yield of seed cotton (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of 5 fields ± (s.d.)</td>
<td>51,889 (6,565)</td>
<td>19.1% (6.7%)</td>
<td>13.9</td>
<td>4.55</td>
<td>712,674 (119,028)</td>
</tr>
<tr>
<td>Correlation coefficient (r) with PP and its significance (*P&lt;0.05)</td>
<td>-0.85(^*)</td>
<td>-0.60(^*)</td>
<td>-0.48(^*)</td>
<td>0.07NS</td>
<td>-0.07NS</td>
</tr>
</tbody>
</table>

\(^1\) calculated as s.d. of average of plants/10 row divided by the average expressed as a percentage. The component ‘plants/10 m row’ was the average of 20 samples in each of the 20 sampled fields (400 samples).

For the five lowest yielding fields this variability was 32.8% (r = -0.40, p<0.05), but for the five highest yielding fields this was only 19.1% (r = -0.85, p<0.05). That is yields were more variable in fields with lower plant populations.

Both high and low yielding fields became less variable as plant populations increased, but this trend was more pronounced in high yielding fields. Low yielding fields had more variable as well as lower plant populations. Anastassiou-Lefkopoulou and Sotiriadis (1984) also found that variability of plant yield, expressed by the coefficient of sensitivity, (c.v. of yield as a percentage of yield) was negatively correlated to plant population from 2.7-17.6 plants/m\(^2\), indicating that the stability of production increases with an increase in plant
population. One of the causes of variability in fields surveyed was the presence of gaps of around 50 cm in the rows. At low plant populations, uniformity of plantings without gaps is important. Lower plant populations may be recommended where stands are uniform (Lee, 1968; Marani et al., 1974).

Amongst the five lowest yielding fields surveyed, there was a high negative correlation between plant population and the number of bolls per plant and boll weight, and a weaker negative relationship between population and yield (Table 4.2). This suggests that in these relatively low yielding fields, factors are present that cause the plant to compensate for increased population by reducing the other two main yield determinants. In Central Asia, these factors may include compaction and poor root penetration (Avtonomov and Blijina, 1968; Batekaev et al., 1984; Sergaziev, 1977), salting (Rejepov et al., 1991), and limited water and soil nutrients (Rejepov et al., 1985; TACIS, 1999).

Where there are apparently fewer limiting factors, as in the five highest yielding fields, a much higher plant population can be reached before the plant has to compensate by reducing individual plant production (Table 4.3). This agrees with the experiments reported by Brown (1971), showing an increase in yield up to 95,000 p/ha where moisture was not limiting. Where it was limiting, optimum plant densities were much lower.

Cotton fruit production on an individual plant basis (squares, numbers of immature and mature bolls) is inversely related to plant population (Jones and Wells, 1997; Hoskinson et al., 1972; Mass, 1997; Wanjura and Bilbro, 1977). More specifically first fruiting position open bolls, the crucial fruiting position in determining cotton plant yields (Bourland et al., 1992a, b; Bourland et al., 1990; Bourland et al., 1991; Heitholt, 1997), decreases with increased plant population (Bednarz et al., 2000). The additional plant numbers in the higher
populations, however, result in more first position fruit on an area basis (Bednarz et al., 2000), or in general more flowers and yield on a per area basis (Anastassiou-Lefkopoulou and Sotiriadis, 1984).

A number of studies have found boll size is inversely related to plant populations (Baker, 1976; Bridge et al., 1973; Buxton et al., 1979; Fowler and Ray, 1977; Galanopoulou-Sendouca et al., 1980; Hawkins and Peacock, 1971; Hawkins and Peacock, 1973; Jones and Wells, 1997; Johnson and Walhood, 1972; Rao and Weaver, 1976; Smith et al. 1979). However, Kerby et al. (1990a) and Samra et al. (1985) found no variation in lint/boll at increasing plant populations.

From the results of the survey; and from previous work carried out in Turkmenistan and elsewhere (Hearn, 1972c; Kudratullaev et al., 1981; TACIS, 1999), it may be concluded that plant populations on farms where good management and inputs of water and fertilizer are available are possibly only one-half of optimum.

The focus of this thesis is plant population, a factor that is within the ability of the individual farmer to control. From the results presented above, this factor will probably be limiting on farms where soil compaction, nutrients and water do not represent a constraint to yield.

The factors that appear to be constraining yield in low yielding fields, like soil compaction in the ‘plough pan’ found throughout all Central Asian cotton soils (TACIS, 1997), require equipment that is not available to individual farmers or inputs like fertilizers and water that are provided by the state and are therefore out of the control of individual farmers. These factors are therefore not the focus of this thesis. The negative correlations found in these low yielding fields between plant population and bolls/plant and boll weight also indicates the
importance of correct plant populations in these fields too. Experiments in low yielding fields were not, however, conducted or reported in this thesis.

It may also be suggested that, if inputs are sub-optimal, it may be that farmers have learned by experience that there is no benefit in populations higher than those found in the five lowest yielding fields of the survey.

A series of experiments, reported in Chapters 5 and 7 of this thesis, was planned for the 2002 season to determine the optimum plant population for some of the more common or promising cultivars planted in Ahal and Mary Velayats. Further experiments, reported in Chapter 6 of this thesis, were planned to determine the reasons for the low plant population reported in this Chapter.
5.1 Introduction

Studies of plant population in Turkmenistan in the 1970s and 1980s indicated that populations of 100-110,000 plants/ha gave maximum yields for a wide range of cotton genotypes, although this may increase to 180,000 plants/ha for long staple cultivars under certain conditions (Bakasov, 1977; Bakasov and Yagmurov, 1974; Bakasov et al., 1976; Kudratullaev, 1981; Kudratullaev et al., 1981; Kurbangeldiev, 1985). This period of research preceded independence from Russia, at a time when many of the cultivars used were from Uzbekistan. Since independence, the original Turkmen suite of medium-staple Uzbek cultivars has been considerably changed by selection for early maturity and productivity (A. Babaev, Senior Plant Breeder, ARPEC, pers. comm. 2001). Because genotype affects yield response to population (Heitholt, 1994; Heitholt et al., 1992), new research into plant population is needed.

In cotton producing countries like the United States and Australia, the introduction of new no-tillage cotton production systems has also necessitated re-examination of optimum plant populations for new tillage methods (Segarra et al., 1991; Smart and Bradford, 2000). The popularity of genetically modified cotton amongst producers also indicates that plant population effects on cotton production need to be re-assessed (J. Marshall, Cotton Seed Distributors, Narrabri, unpublished data).

The survey of cotton fields in the Ahal region of Turkmenistan in 2001, reported in Chapter 4, revealed that plant populations for medium staple cultivars were in the range 20,000-
60,000 plants/ha (mean 45,000 plants/ha), well below the optimum of 100-110,000 plants/ha reported from early studies in Turkmenistan. It was concluded that plant populations on farms may be much lower than optimum and contribute to low yields, although there have been no experiments to establish the optimum population for modern Turkmen cultivars. The effect of plant population on cotton yield on such farms was therefore the focus of experimentation in 2002.

Not only were populations low in the field survey, but they were highly variable. This variability was largely attributed to gaps in the rows of the fields surveyed, rather than to large areas within fields having low populations. Two factorial experiments with plant population and gaps as the factors were therefore undertaken at ARPEC and the CRI to evaluate the contribution of these factors to low yields.

A notable feature of the survey results was that, where yields were low and management was presumed to be poorer, there was a significant negative correlation between the yield components of boll weight and number of bolls per plant and population. That is, there may be an interaction between plant population and the standard of crop management in determining yield response to increased plant populations. The management factor regarded as most important in Turkmenistan in this regard is irrigation (Regepov et al., 1985; TACIS 1999). Therefore, the effect of irrigation on optimum plant population was examined in a plant population x irrigation trial in 2002. In Turkmenistan most of the irrigation water used in cotton cultivation arrives at the field from the Amu Daraya River via the Karakum Canal. However, in Mary Velayat, in which the Turkmenistan Cotton Research Institute is located, approximately half the water used is supplied by the Murgab River, which rises in Afghanistan. In 2001 the Murgab River supply failed for the first time in many years. As
irrigation water is expected to be a limiting factor for cotton production in Mary Velayat, this trial was located at the CRI.

In Turkmenistan, several experiments on plant population using long-staple cultivars have shown delayed maturity (Bakasov and Yagmurov, 1974; Kurbangeldiev, 1985). Earliness is important in cotton crops, leading to lower production costs, early land preparation for the next crop, harvesting efficiency, escape from late season pests and increased fibre quality at earlier harvest dates (Galanopoulou- Sendouca, 2002). Therefore, in the experiments reported in this Chapter the effects of plant population on maturity were measured where possible. Also, as plant population may affect quality attributes of cotton (Jones and Wells, 1997, 1998) these were also measured where possible. In this thesis the COTMAN system is used to characterize or explain maturity and yield responses to plant population (see Chapter 8). As the COTMAN system is based on flowering patterns, phenological data are also reported here.

The experiments in this Chapter aimed to determine optimum cotton populations in modern Turkmen cotton cultivars under both well-irrigated and water-limited conditions (to test for any interaction), and to test the hypothesis that the low field population associated with gaps in rows of cotton could be a major contributor to the low yields observed in the field survey reported in Chapter 4.
5.2 Materials and Methods

5.2.1 Plant density x gap experiment at ARPEC

The effect of two factors on the yield, fibre quality and phenology of the modern medium staple cultivar Turkmenbashi 1 were investigated. The factors were plant population (3, 6, 9, 12 and 15 plants/m²) and gaps within the row (0, 2 and 4 gaps of 50 cm per 10m row). Design was a 5 x 3 factorial as a randomized complete block. Plot size was 3 rows (90 cm spacing) x 10 m with four replications. Further details are given in Chapter 3.

5.2.2 Plant population x gap experiment at CRI

The experiment was identical to that at ARPEC except that plant population (2, 5, 8, 11 and 14 plants/m²) varied slightly from ARPEC due to advice of scientists at the CRI, and the modern medium staple cultivar Iolatan 7 was used.

The difficulties in recording plant phenology and analyzing fibre samples at this site are outlined in Section 3.4.

5.2.3 Plant population x irrigation frequency experiment at CRI

This experiment investigated growth and yield responses to 5 plant populations (2, 5, 8, 11 and 14 plants/m²) at four irrigation frequencies (0, 1, 2 and 5 irrigations) using the cultivar Iolatan 7. The design was a 5 x 4 split plot with irrigation treatments as main plots and plant population as sub-plots in a randomised complete block with four replications. Plot size was 4 rows (90 cm spacing) x 10 m. Further agronomic details are given in Chapter 3. GOT,
fibre yields, length, uniformity, strength and micronaire could not be calculated at this site as they were at ARPEC. However, Turkmen scientists from the CRI made phenological observations in this experiment.

5.3 Results and Discussion

5.3.1 Plant population x gap experiment at ARPEC, Anau (2002)

The effect of plant population on yield of seed cotton and cotton fibre were significant (P<0.05). Despite an arithmetic tendency to decrease with increasing number of gaps, there was no significant effect of gaps on either measure of yield (P>0.05) (Table 5.1). That is, yield was a function of population alone, with gaps in rows at any given population having no effect at the levels studied. The ability of the cotton plant to compensate for irregularity of plant distribution or gaps in the crop canopy by greater productivity of existing plants has been reported (Lee, 1968; Marani et al., 1974) and may be a physiological consequence of this inherently perennial crop being grown annually (Cothren, 1999). This compensation (in this case for up to 20% of area on a per row basis) explains this experimental result. As there was also no significant effect of gaps on maturity, fibre or phenological characteristics in this experiment either (P>0.05), presentation of data for these characteristics is based on the combined data for the gap treatments.

There was no significant interaction between factors on yield and yield components, quality or phenological characteristics in the experiment.

The highest yield of seed cotton and fibre was obtained in the treatment with a planted population of 120,000 plants/ha (final plant density of 101,000 plants/ha), although the yield
increase between 90,000 and 120,000 plants/m\(^2\) was not statistically significant (Table 5.1). The increase from 60,000 to 120,000 was significant (P<0.05).

Table 5.1  Effect of plant population and gaps in rows on seed cotton and lint yields at ARPEC, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Gaps per 10-m row</th>
<th>Sown plant population (plants/ha)</th>
<th>Final plant populations (plants/ha)</th>
<th>Seed cotton yield (kg/ha)</th>
<th>Fibre yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30,000</td>
<td>60,000</td>
<td>90,000</td>
<td>120,000</td>
</tr>
<tr>
<td></td>
<td>28,000</td>
<td>55,000</td>
<td>76,000</td>
<td>101,000</td>
</tr>
<tr>
<td>0</td>
<td>1929</td>
<td>2809</td>
<td>3038</td>
<td>2851</td>
</tr>
<tr>
<td>2</td>
<td>2022</td>
<td>2423</td>
<td>2904</td>
<td>3122</td>
</tr>
<tr>
<td>4</td>
<td>1714</td>
<td>2512</td>
<td>2739</td>
<td>3221</td>
</tr>
<tr>
<td>Mean</td>
<td>1889</td>
<td>2581</td>
<td>2893</td>
<td>3064</td>
</tr>
</tbody>
</table>

Least significant difference for population means (P<0.05) is 479 kg seed cotton /ha and 207 kg/ha for fibre yield. The effect of gaps was not statistically significant (P>0.05).

Fibre production increased by 74% (62% seed cotton) from a planted population of 30,000 to 120,000 plants/ha. The planted population of 30,000 plants/ha resulted in a final plant population of 28,000 plants/ha, which was similar to some fields in Ahal Velayat observed in the 2001 field survey (Chapter 4).

The data for population and yield were regressed to determine optimum planting populations, using individual plot data (actual plot populations). The results are given in Figures 5.1 and 5.2 (in these and all future figures, plant population data are given as plants/m\(^2\) to make the horizontal axis more legible). The data were fitted most closely by a quadratic function, as described by Gutstein (1973) for cotton plants with a short reproductive season or early maturity, rather than the asymptotic function for cotton with a long reproductive period. A typical asymptotic function is reported for conventional G.
*hirsutum* cultivars in Australia (Constable, 1997). However, new genetically modified cultivars grown in Australia with low insect attack and ‘tipping out’ may have a more parabolic response curve (G. Constable, Cotton Research Institute Narrabri, pers. comm. 2003). From the regression equations in Figures 5.1 and 5.2 the optimum final population for seed cotton and fibre yield is 10 plants/m$^2$ (100,000 plants/ha), or an initial population (measured just after emergence) of 12 plants/m$^2$ (120,000 plants/ha). Initial and final plant populations are given in Table 5.1. The regressions for both seed cotton and fibre yield against population are relatively flat and, given the variability in the data, the optimal plant density of 10 plants/m$^2$ should be taken as ‘indicative’.

![Figure 5.1](image_url)

**Figure 5.1** Effect of final plant population on yield of seed cotton of the cultivar Turkmenbashi 1 in a plant population x gap experiment at ARPEC, Turkmenistan in 2002. (The regression equation with standard errors for the curve is $y = -22.1(\pm 8.5)x^2 + 439(\pm 122)x + 829(\pm 394)$ with $r^2 = 0.38$, P,0.01)
Increased yield with increased population was associated with greater numbers of bolls produced per unit area (Table 5.2). Boll weight (average for all treatments 4.55g) was not significantly affected by plant population in this experiment, as previously reported by Kerby et al. (1990a), but contrary to the results of experiments reported in Turkmenistan by Kudratullaev et al. (1981). The difference between results reported by Kerby et al. and those of Kudratullaev et al. may be due to sub-optimal levels of nitrogen and other inputs in the Turkmen experiments. That is, effects of population on boll weight may only occur in N-deficient crops, an explanation that is considered again later in this chapter. Ginning out-turn (GOT) was not affected by plant density (average for all treatments 39%), as reported in Turkmenistan (Kudratullaev et al., 1981) and other parts of the world (Guinn 1982a, 1985a; Jones and Wells, 1997; Hoskinson et al., 1972; Mass, 1997; Wanjura and Bilbro, 1977).
Table 5.2  Effect of plant population on yield and yield components of the cultivar Turkmenbashi 1 at ARPEC, Turkmenistan in 2002.

<table>
<thead>
<tr>
<th>Population (plants/ha)</th>
<th>Bolls/plant</th>
<th>Bolls/ha (x1000)</th>
<th>Boll weight (g)</th>
<th>GOT (%)</th>
<th>Yield seed cotton (kg/ha)</th>
<th>Yield fibre (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sown (target)</td>
<td>Final</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30,000</td>
<td>27,685</td>
<td>15.2</td>
<td>418</td>
<td>4.54</td>
<td>0.38</td>
<td>1,889</td>
</tr>
<tr>
<td>60,000</td>
<td>55,278</td>
<td>10.2</td>
<td>560</td>
<td>4.60</td>
<td>0.39</td>
<td>2,581</td>
</tr>
<tr>
<td>90,000</td>
<td>76,296</td>
<td>8.1</td>
<td>620</td>
<td>4.66</td>
<td>0.39</td>
<td>2,894</td>
</tr>
<tr>
<td>120,000</td>
<td>101,204</td>
<td>6.9</td>
<td>688</td>
<td>4.45</td>
<td>0.41</td>
<td>3,065</td>
</tr>
<tr>
<td>150,000</td>
<td>106,204</td>
<td>6.1</td>
<td>636</td>
<td>4.52</td>
<td>0.39</td>
<td>2,876</td>
</tr>
<tr>
<td>l.s.d. (0.05)</td>
<td>5,757</td>
<td>1.8</td>
<td>100</td>
<td>NS¹</td>
<td>NS¹</td>
<td>479</td>
</tr>
</tbody>
</table>

¹ Treatment effects not significant, (P>0.05)

Increased plant density significantly decreased both the numbers of green bolls per plant and the percentage of green bolls at harvest (P<0.05) (Table 5.3). These results are similar to those reported by Smith et al. (1979).

Population also significantly affected numbers of open bolls per plant at 127DAP, 138DAP and 145DAP. However as the number of bolls per plant decreased significantly with increased plant population (Table 5.3, only characteristics for which there was a significant treatment effect, P<0.05, listed), the percentage of open bolls and percentage of green bolls, rather than numbers per plant, are a better measure of maturity in this experiment. Increased plant populations did not affect percentages of open bolls at these dates (average 18%, 61% and 87% for 127DAP, 138DAP and 145DAP).

Gaps in the field up to up to four 50-centimeter gaps in a 10-meter row had no significant effect on maturity in this experiment (data not presented). Nor was there a significant interaction between plant population and gaps in field in affecting plant maturity in this experiment.
Table 5.3  Effect of plant population on yield and maturity characteristics of the cultivar Turkmenbashi 1 at ARPEC, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Initial plant population /ha</th>
<th>No of green bolls per 10 plants</th>
<th>% Green bolls</th>
<th>Open bolls /plant 127DAP</th>
<th>Open bolls /plant 138DAP</th>
<th>Open bolls /plant 145DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>13</td>
<td>8.9</td>
<td>1.96</td>
<td>8.00</td>
<td>12.62</td>
</tr>
<tr>
<td>60,000</td>
<td>3</td>
<td>2.6</td>
<td>1.70</td>
<td>5.87</td>
<td>8.65</td>
</tr>
<tr>
<td>90,000</td>
<td>1</td>
<td>1.5</td>
<td>1.74</td>
<td>5.11</td>
<td>6.85</td>
</tr>
<tr>
<td>120,000</td>
<td>1</td>
<td>0.8</td>
<td>1.18</td>
<td>4.37</td>
<td>6.06</td>
</tr>
<tr>
<td>150,000</td>
<td>1</td>
<td>1.6</td>
<td>1.18</td>
<td>3.81</td>
<td>5.12</td>
</tr>
<tr>
<td>l.s.d (0.05)</td>
<td>4.1</td>
<td>3.6</td>
<td>0.54</td>
<td>0.82</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Plant density had significant effects on some cotton quality attributes. Upper half mean length and micronaire were significantly (P<0.05) affected by plant population (Table 5.4), but no other quality attribute was affected (average values for all treatment means for 100 seed weight = 10.13 g; Pressley Index Strength = 7.86 Pressley Units; Mean Length = 0.89 inches; Uniformity Index = 82%; Short Fiber Index = 16.74). Length and micronaire were both reduced at sown populations of 90,000 and greater. Plant population affected micronaire in experiments conducted by Gannaway et al. (1995) and Johnson and Walhood (1972). As micronaire is a measure of crop maturity as much as fibre quality (Benedict et al., 1999), the effect of treatment differences in plant population on maturity described above may explain the decreases in micronaire observed in the experiment. No other fibre properties were affected in this experiment. This agrees with the findings of Baker (1976); Bridge et al. (1973); Briggs and Patterson (1970); Hawkins and Peacock (1973); Gannaway et al. (1995) and Johnson and Walhood (1972).

There were no significant effects of gaps on fiber quality.
Despite differences in upper half mean length and micronaire being significant in this experiment, they were quite small and would not have resulted in a lowering of grade or economic penalty to the cotton in the higher treatment levels. Grade would have been Soviet Grade IV (low middling – strict good ordinary or 35, 36 USDA grade) at all populations on the basis of UHML. Fineness would have improved from ‘coarse’ at lowest population to ‘average’ at all others. All samples would have been classed ‘1 YAKSHI’ in the Turkmen classification (TACIS 2002a).

Table 5.4  Effect of Plant Population on Quality Characteristics of the cultivar Turkmenbashi 1 at ARPEC, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>PP/ha (planted) '000</th>
<th>Micronaire</th>
<th>Length - UHML</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>4.73</td>
<td>1.11</td>
</tr>
<tr>
<td>60</td>
<td>4.66</td>
<td>1.08</td>
</tr>
<tr>
<td>90</td>
<td>4.45</td>
<td>1.06</td>
</tr>
<tr>
<td>120</td>
<td>4.46</td>
<td>1.09</td>
</tr>
<tr>
<td>150</td>
<td>4.45</td>
<td>1.06</td>
</tr>
<tr>
<td>l.s.d. (0.5)</td>
<td>0.24</td>
<td>0.04</td>
</tr>
</tbody>
</table>

As crop phenological characteristics in this experiment were recorded as Nodes Above the White Flower (NAWF), and as NAWF=5 is an accepted measure of crop maturity or physiological ‘cut-out’ (see Chapter 2), there is a strong agreement between results on the basis of plant maturity and those based on phenology. Plant population had a significant affect on crop phenological characteristics in this experiment, effecting maximum number of fruiting nodes at 77DAP; nodes above the white flower on the main stem at 86, 91 and 105 (but not 112) days after planting and days after planting to NAWF=5 (Table 5.5, only characteristics for which there was a significant treatment effect, P<0.05, listed). As the rate of change of NAWF was not significantly affected by plant population, differences in days to NAWF=5 (physiological cut-out) can be accounted for by differences in maximum numbers of squaring nodes at 77DAP (9.98 at 30,000 p/ha to 8.97 at 150,000 plants/ha,
P<0.01). These results are in accord with those of Buxton et al. (1977) and more recent research by Bednarz et al. (2000). They reflect larger plastochrons at high populations than those at low (Munro, 1971; Munro and Farbrother, 1969). These may result from lower total available carbohydrate levels in leaves at high plant populations than in leaves of cotton grown at lower densities (Saleem and Buxton, 1976).

Experimental plots took 103 days to ‘cut-out’ at a planting rate 30,000 plants/ha compared to 100 days at 120,000 plants/ha. These results agree with the results reported by Buxton et al. (1977) and generally agree with the effects on maturity reported above (that is increased plant population promotes crop maturity). However, they are at odds with local research with long staple cultivars that has found increasing plant population delays maturity (Bakasov and Yagmurov, 1974; Kurbangeldiev, 1985). As Buxton et al. (1977) report results using medium staple cultivars in their experiments, the differences with research reported in Turkmenistan may be due to the different relationship between vegetative and fruiting growth in the two species (Kerby and Hake, 1996).

Gaps in the rows had no significant effect on phenological properties of plants in the various treatments. There was no significant interaction effect between factors on phenological properties in the experiment.

Average maximum square number was 9.6 in this experiment for plants that had a white flower, compared to 9.25 for the apogee of the COTMAN ‘target development curve’ (Oosterhuis et al., 1996b). Rate of descent of the NAWF ‘curve’ was 0.173 nodes per day compared to 0.213 nodes per day in the COTMAN ‘target development curve’.
A more succinct representation of the phenological data arising from the experiment is given as a series of COTMAN 'curves' for each treatment in Chapter 8.

Table 5.5  Effect of plant population on the phenological characteristics of the cultivar Turkmenbashi 1 at ARPEC, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>PP/ha (planted)</th>
<th>SN 77 DAP</th>
<th>NAWF 86 DAP</th>
<th>NAWF 91 DAP</th>
<th>NAWF 100 DAP</th>
<th>NAWF 105 DAP</th>
<th>86 DAP to NAWF=5 (days)</th>
<th>DAP to NAWF=5</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>9.98</td>
<td>8.16</td>
<td>7.91</td>
<td>6.55</td>
<td>5.84</td>
<td>17.21</td>
<td>103.21</td>
</tr>
<tr>
<td>60</td>
<td>9.84</td>
<td>7.71</td>
<td>7.60</td>
<td>6.20</td>
<td>5.78</td>
<td>15.40</td>
<td>101.40</td>
</tr>
<tr>
<td>90</td>
<td>9.78</td>
<td>7.46</td>
<td>7.44</td>
<td>5.79</td>
<td>5.17</td>
<td>13.84</td>
<td>99.84</td>
</tr>
<tr>
<td>120</td>
<td>9.64</td>
<td>7.23</td>
<td>7.18</td>
<td>5.82</td>
<td>5.01</td>
<td>13.63</td>
<td>99.63</td>
</tr>
<tr>
<td>150</td>
<td>8.97</td>
<td>7.29</td>
<td>6.99</td>
<td>5.68</td>
<td>4.95</td>
<td>13.54</td>
<td>99.54</td>
</tr>
<tr>
<td>l.s.d. (0.05)</td>
<td>0.67</td>
<td>0.35</td>
<td>0.35</td>
<td>0.38</td>
<td>0.40</td>
<td>2.07</td>
<td>2.07</td>
</tr>
</tbody>
</table>

1 number of nodes with sympodial branches carrying first position squares at 77 days after planting
2 number of nodes above the first white flower 86 days after planting
3 number of days after planting till there were 5 nodes above the first white flower, or ‘cutout’

5.3.2 Plant population x gap experiment at CRI, Iolatan (2002)

Plant population had a significant effect on yield of seed cotton of Iolatan 7 at CRI (P<0.05), but gaps in the field had no significant effect on yield (P≥0.05) (Table 5.6). However, there was a significant interaction (P<0.05) between gaps and plant population, unlike the similar experiment at ARPEC, Anau. This difference may possibly be explained by the spreading growth habit of Iolatan 7 compared to the upright form of Turkmenbashi 1.
Table 5.6  Effect of plant population and gaps in rows on seed cotton yields of Iolatan 7 at CRI, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Gaps per 10-m row</th>
<th>Sown plant population (plants/ha)</th>
<th>20,000</th>
<th>50,000</th>
<th>80,000</th>
<th>110,000</th>
<th>140,000</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1659</td>
<td>2691</td>
<td>3546</td>
<td>4497</td>
<td>5056</td>
<td>3490</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1927</td>
<td>2606</td>
<td>4223</td>
<td>4805</td>
<td>4047</td>
<td>3522</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1520</td>
<td>2311</td>
<td>3791</td>
<td>4175</td>
<td>3731</td>
<td>3106</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1702</td>
<td>2536</td>
<td>3853</td>
<td>4492</td>
<td>4278</td>
<td>3678</td>
<td></td>
</tr>
</tbody>
</table>

Least significant difference for population means (P<0.05) is 669 kg seed cotton /ha. The effect of gaps was not statistically significant (P>0.05).

The highest yield of seed cotton was obtained at the planted population of 110,000 plants/ha (final plant population 105,000 plants/ha), an increase in seed cotton production of 164% over that obtained at a target population of 20,000 plants/ha (final plant population of 29,000 plants/ha). Significant differences were between the 20,000 and 50,000 sown plants/ha treatments and all other treatments, but not between the 80,000 plants/ha treatment and the two higher population treatments. Final plant populations for the two lowest treatments in this experiment (29,000 plants/ha and 55,000 plants/ha) were very similar to those of the experiment conducted at ARPEC (28,000 plants/ha and 55,000 plants/ha), despite the two lowest initial plant populations being different at the two sites (30,000 p/ha and 60,000 p/ha at ARPEC, compared to 20,000 p/ha and 50,000 p/ha at CRI).

The increases in yield associated with increasing plant population were associated with greater numbers of bolls produced per unit area (Table 5.7) despite a small but significant decrease in boll weight at this site (Table 5.7).
Table 5.7 Effect of plant population on the yield and yield components of the cultivar Iolatan 7 in the plant population x gap experiment at CRI, Turkmenistan in 2002.

<table>
<thead>
<tr>
<th>Population (plants/ha)</th>
<th>Bolls/plant</th>
<th>Boll number (1000/ha)</th>
<th>Boll weight (g)</th>
<th>Yield seed cotton (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sown (target)</td>
<td>Final</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20,000</td>
<td>28,889</td>
<td>10.7</td>
<td>418</td>
<td>5.49</td>
</tr>
<tr>
<td>50,000</td>
<td>55,093</td>
<td>8.6</td>
<td>560</td>
<td>5.40</td>
</tr>
<tr>
<td>80,000</td>
<td>79,167</td>
<td>9.1</td>
<td>620</td>
<td>5.36</td>
</tr>
<tr>
<td>110,000</td>
<td>105,093</td>
<td>8.3</td>
<td>688</td>
<td>5.17</td>
</tr>
<tr>
<td>140,000</td>
<td>127,407</td>
<td>6.6</td>
<td>636</td>
<td>5.08</td>
</tr>
<tr>
<td>l.s.d. (0.5)</td>
<td>4,977</td>
<td>1.7</td>
<td>100</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Yield was regressed against population so that optimal populations could be predicted (Figure 5.3), once again using a quadratic function \( r^2 = 0.66 \) as described for Gutstein (1973) for cotton plants with a short reproductive season or early maturity. The highest yields occur at a final plant population of 10 plants/m², although it is clear that there is little or no benefit in achieving populations greater than about 10 plants/m² (the mean yield at 14 plants/m² was statistically no greater than at 11 plants/m², Table 5.6). The failure of the curve to ‘peak’ within the range of treatment populations, as it did for the cultivar Turkmenbashi 1 grown at ARPEC (see Figures 5.1 and 5.2), may be due to the longer maturity of the cultivar Iolatan 7 grown at CRI. An asymptotic curve has been fitted to the same data with no loss in regression \( r^2 = 0.66 \). This adds support to the proposition that Iolatan 7 may be classed as a ‘long season’ cultivar (Gutstein, 1973).
Figure 5.3  Effect of final plant population on yield of seed cotton of the cultivar Iolatan 7 in the plant population x gap experiment at CRI, Turkmenistan in 2002 (The regression equation with standard errors for the curve is $y = 84(\pm 503) 592(\pm 138)x - 18(\pm 8)x^2$, $R^2=0.66$, $P<0.01$)

Regressing mean treatment yields (each point on the curve is the average of 12 plots) rather than plot yields, gives a response curve of the form:
\[
y = -30.1(\pm 14.7)x^2 + 761(\pm 234)x - 398(\pm 808) \quad (R^2 = 0.96, P<0.01) \text{ (Figure 5.4b)}
\]

This is a quadratic, like that determined by Kumar (1988) in Nigeria:
\[
y = 707.75+3.25x-0.0113x^2 \quad (R^2=0.99),
\]
and that developed from mean yields in the population x gap experiment at ARPEC reported above:
\[
y = -25(\pm 5.9)x^2 + 474(\pm 82)x + 752(\pm 246) \text{ with } R^2 = 0.98, P<0.01
\]

The lines of best fit for mean yields for Iolatan 7 at CRI, and those of Turkmenbashi 1 at ARPEC, are given in Figure 5.4. The failure of the curve to ‘peak’ within the range of treatment populations, as it did in the experiment at ARPEC, indicates the longer maturity of the cultivar Iolatan 7 (Gutstein, 1973).
Figure 5.4  Effect of final plant populations on mean treatment yields of Turkmenbashi 1 in the population x gap experiment at ARPEC (a – regression equation \( y = -25(\pm 5.9)x^2 + 474(\pm 82)x + 752(\pm 246) \) with \( R^2 = 0.98, P,0.01 \)) and of Iolatan 7 (b – regression equation \( y = - 30.1(\pm 14.7)x^2 + 761(\pm 234)x - 398(\pm 808) \) with \( R^2 = 0.96, P,0.01 \)) in the population x gap experiment at CRI, Turkmenistan in 2002 (right).

The small decrease in boll weight with increased plant population noted in this experiment (Table 5.7) is contrary to the experimental results at ARPEC, Anau (Table 5.2), but consistent with experiments reported by a number of other researchers (Baker, 1976; Bednarz et al., 2000; Bridge et al., 1973; Buxton et al., 1979; Fowler and Ray, 1977; Galanopoulou-Sendouca et al., 1980; Gannaway et al., 1995; Hawkins and Peacock, 1971; Hawkins and Peacock, 1973; Jones and Wells, 1997; Johnson and Walhood, 1972; Rao and Weaver, 1976; Smith et al. 1979) and also some local experiments (Kudratullaev et al., 1981).

Interplant competition commences shortly after adjacent plants make physical contact within and across the row (Maas, 1997). As each plant competes with its neighbor for sunlight (Pegelow et al., 1977; Ehlig and Le Mert, 1973; Patterson et al., 1978) or for
nitrogen (Pettigrew and Meredith, 1997; Wullschleger and Oosterhuis, 1990b) its own fruiting potential becomes increasingly limited.

A possible reason for the different responses of boll weight to plant population at the CRI site compared to ARPEC, may be the amount or insufficiency of nitrogen fertilizer added at CRI, which was only one half that added at ARPEC. Pettigrew and Meredith (1997) report a high nitrogen demand of seeds developing in maturing bolls and suggest this may lead to a relocation of leaf nitrogen. Studies by Bondada et al. (1997) indicate that the capsule wall is a reservoir of nitrogen when bolls are young, followed by lint and seed as the boll develops. All of these components of the boll are nitrogen ‘sinks’ and their growth and development is related to this element. Nitrogen deficient plants are thus likely to suffer reduced boll size.

In another study conducted by Bondada (1994), using $^{15}$N accumulation in various canopy strata, canopy photosynthesis was found to be strongly influenced by soil nitrogen and was correlated with NAWF and yield. Middle canopy layers had higher $^{15}$N accumulation due to higher boll load and increased leaf area. Similar findings were reported by Mullins and Burmester (1990).

Changes in boll weight with increased plant population have been found to depend on the yield level of the crop compared to the potential yield (Hearn, 1972c). Overall, it appears that the effects of competition, associated with increased plant population, will be most likely to result in reduced boll weight in N-deficient crops. It is suggested that the CRI crops were deficient in N, despite the yields higher than those at ARPEC. The different correlations between plant population and boll weight in high yielding and low yielding fields, reported in Chapter 4, also supports this interpretation.
When plant population is low, fruiting branches are longer and develop more flowering positions and more vegetative branches than at higher plant populations. However, at high plant population, longer flowering branches are eliminated (Kerby et al., 1990a). Consequently, as plant population increases the number of fruiting positions on each plant declines. In the CRI experiment, the number of bolls/plant (Table 5.7) decreased with increase plant population in accordance with many past reported experiments in Turkmenistan and overseas as reported above.

The decreases in bolls/plant with increased plant population recorded in this experiment conducted at CRI were not as dramatic as at ARPEC (Table 5.7 c.f. Table 5.2). This may be due to the difference in maturity and yield of the cultivars used in the two experiments. The cultivar Turkmenbashi 1 matured rapidly at ARPEC but the cultivar Iolatan 7 was slower maturing and higher yielding at CRI.

Plant population had a significant effect on the number of green bolls/plant in each treatment at harvest in this experiment, but not on the percentage of green bolls at harvest (see Table 5.8). As the percentage of green bolls is the best measure of maturity in this experiment, it is concluded that plant population had no effect on the maturity of Iolatan 7 at this site. The difference in effects on maturity at the two sites (compare Table 5.8 to Table 5.3) may reflect the differences in maturity of the two cultivars rather than site differences relating to soil nitrogen status (Iolatan 7 is later maturing than Turkmenbashi 1).

Gaps in the field had no significant effect on either maturity characteristic, nor were there any significant interaction effects.
Table 5.8  Effect of plant population on maturity characteristics of the cultivar Iolatan 7 in the plant population x gap experiment at CRI, Turkmenistan in 2002.

<table>
<thead>
<tr>
<th>PP/ha (planted) ‘000</th>
<th>Maturity – green bolls absolute no per 10 plants</th>
<th>Maturity - % Green bolls</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>114.5</td>
<td>48.9</td>
</tr>
<tr>
<td>50</td>
<td>74.1</td>
<td>45.5</td>
</tr>
<tr>
<td>80</td>
<td>69.3</td>
<td>42.6</td>
</tr>
<tr>
<td>110</td>
<td>58.8</td>
<td>38.2</td>
</tr>
<tr>
<td>140</td>
<td>68.8</td>
<td>48.6</td>
</tr>
<tr>
<td>l.s.d. (0.5)</td>
<td>30.4</td>
<td>NS¹</td>
</tr>
</tbody>
</table>

¹ Treatment effects not significant, (P>0.05)

5.3.3 Plant population x irrigation frequency experiment at CRI, 2002

The treatment effects on yield and yield components in this experiment are summarized in Table 5.9. Plant population (P<0.01) and irrigation frequency (P<0.05) both affected the yield of seed cotton of Iolatan 7 at CRI in 2002. The interaction between these two factors was not significant (P>0.05) for yield, but was for the yield component boll weight (P<0.01). This latter result supports, in part, the hypothesis developed from the field survey (Chapter 4) that in poorly-managed/irrigated fields there would be a negative correlation between plant population and yield and yield components.

This experiment became an investigation of effects of plant population treatments, the ‘main driver’ of yield of Iolatan 7 and of a weaker irrigation effect on yield.
Table 5.9  Summary of analysis of variance on yield in the plant population x irrigation experiment at CRI, Turkmenistan in 2002

<table>
<thead>
<tr>
<th></th>
<th>Yield of seed cotton</th>
<th>Bolls/plant</th>
<th>Bolls/row</th>
<th>Bolls/ha</th>
<th>Final plant population</th>
<th>Boll weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant population</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Irrigation frequency</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
</tr>
<tr>
<td>Interaction</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
</tr>
</tbody>
</table>

Significance: ** P < 0.01; * P < 0.05
NS – Non-Significant

The data for yield and yield components are given in Table 5.10. Maximum yield of seed cotton was obtained in the treatment 80,000 plants/ha (a final plant density of 77,000 plants/ha), an increase in seed cotton production of 232% over that obtained at a targeted population of 20,000 plants/ha (final plant density of 21,000 plants/ha). Although the main effect for irrigation was significant, there was no further significant response after a single irrigation in this season (Table 5.10). Irrigation became the main driver in this experiment. This may have been due to either the effect of ground water supply in the 2 and 5 irrigations treatments or perhaps to the experimental difficulties discussed in Chapter 3.


<table>
<thead>
<tr>
<th>Number of irrigations</th>
<th>Sown plant population (plants/ha)</th>
<th>Final plant population (plants/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20,000</td>
<td>20,625</td>
</tr>
<tr>
<td></td>
<td>50,000</td>
<td>50,417</td>
</tr>
<tr>
<td></td>
<td>80,000</td>
<td>77,361</td>
</tr>
<tr>
<td></td>
<td>110,000</td>
<td>89,097</td>
</tr>
<tr>
<td></td>
<td>140,000</td>
<td>112,222</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Kg/ha seed cotton ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>891</td>
</tr>
<tr>
<td>1</td>
<td>1004</td>
</tr>
<tr>
<td>2</td>
<td>1285</td>
</tr>
<tr>
<td>5</td>
<td>1391</td>
</tr>
<tr>
<td>Mean</td>
<td>1,143</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Boll weight (g) ²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.39</td>
</tr>
<tr>
<td>1</td>
<td>4.58</td>
</tr>
<tr>
<td>2</td>
<td>4.70</td>
</tr>
<tr>
<td>5</td>
<td>5.11</td>
</tr>
<tr>
<td>Mean</td>
<td>4.69</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Bolls/plant ³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9.5</td>
</tr>
<tr>
<td>1</td>
<td>11.2</td>
</tr>
<tr>
<td>2</td>
<td>13.2</td>
</tr>
<tr>
<td>5</td>
<td>12.9</td>
</tr>
<tr>
<td>Mean</td>
<td>11.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1000 Bolls/ha ⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>204</td>
</tr>
<tr>
<td>1</td>
<td>224</td>
</tr>
<tr>
<td>2</td>
<td>274</td>
</tr>
<tr>
<td>5</td>
<td>272</td>
</tr>
<tr>
<td>Mean</td>
<td>244</td>
</tr>
</tbody>
</table>

¹ Kg/ha seed cotton Lsd P<0.05 for Irrigation, 714 kg/ha; Population 696 kg/ha
² Boll weight (g) Lsd P<0.05 for Irrigation, 0.08; Population, 0.13
³ Bolls/plant Lsd P<0.05 for Irrigation, 2.1; Population 2.5
⁴ 1000 Bolls/ha Lsd P<0.05 for Irrigation, 149; Population, 145.

The effect of population x irrigation frequency was not significant (P>0.05) except on boll weight.

The optimum plant population was determined from the regression of all plot data, rather than treatment means, and was calculated by setting the first derivation of the regression equation between population and yield at zero and then calculating the population for this value.
Setting the first derivative of the equation given in Figure 5.5 at zero, an optimum of 10 plants/m² (100,000 plants/ha) is indicated.

![Graph showing the effect of final plant population on yield of seed cotton](image)

**Figure 5.5**  Effect of final plant population on yield of seed cotton of the cultivar Iolatan 7 in the plant population x irrigation experiment at CRI, Turkmenistan in 2002 (The regression equation with standard errors for the curve is $y = -38(\pm 9.1)x^2 + 759(\pm 126)x - 201(\pm 398)$, $R^2 = 0.51$, P,0.01)

Increases in yield due to increased plant population resulted from greater numbers of bolls produced per unit area (see Table 5.10). A significant decrease in boll weight with increasing population was more than offset by the increase in boll number per hectare (see Table 5.10). The decrease in boll weight with increased plant population was contrary to the experimental results at Anau (Table 5.2), but in accordance with the population x gap experiment at CRI reported above and others previously conducted in Turkmenistan (Kudratullaev et al., 1981). Boll weight responded positively to increased numbers of irrigations (Table 5.10).
As in the plant density x gap experiment at CRI reported earlier, the reason for the different responses of boll weight to plant population at this site compared to ARPEC may be the level of nitrogen fertilizer added at CRI (Pettigrew and Meredith, 1997) which was only one half that added at ARPEC.

Increased irrigation frequency significantly increased boll weights and the interaction of plant population with irrigation frequency was significant for this characteristic (see Table 5.10).

Plant population significantly affected maturity in this experiment, as judged by the number of green bolls per 10 sampled plants at harvest and on the percentage of green bolls at harvest. Both decreased with increasing plant populations (Tables 5.12). Irrigation frequency had no significant effect on either maturity characteristic nor was there a significant interaction recorded between the two factors in the experiment (Table 5.11).

**Table 5.11** Summary of analysis of variance on maturity in the plant population x irrigation experiment at CRI, Turkmenistan in 2002

<table>
<thead>
<tr>
<th></th>
<th>Maturity – green bolls absolute no per 10 plants</th>
<th>Maturity - % Green bolls</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant population</strong></td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>Irrigation</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>interaction</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Significances **, * for p < 0.01; 0.01 < p < 0.05
NS – Non-Significant
Table 5.12  Effect of plant population on maturity characteristics of the cultivar Iolatan 7 in the plant population x irrigation frequency experiment at CRI, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Sown population (plants/ha)</th>
<th>Maturity (green bolls / 10 plants)</th>
<th>Maturity (% Green bolls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20,000</td>
<td>173.6</td>
<td>57.6</td>
</tr>
<tr>
<td>50,000</td>
<td>81.1</td>
<td>40.1</td>
</tr>
<tr>
<td>80,000</td>
<td>54.6</td>
<td>32.6</td>
</tr>
<tr>
<td>110,000</td>
<td>30.6</td>
<td>26.4</td>
</tr>
<tr>
<td>140,000</td>
<td>27.1</td>
<td>24.3</td>
</tr>
<tr>
<td>l.s.d. (0.05)</td>
<td>33.8</td>
<td>9.5</td>
</tr>
</tbody>
</table>

A summary of the ANOVA for the effects of plant population and number of irrigations on phenological characteristics of Iolatan 7 in this experiment are given in Table 5.13. The number of irrigations had a significant affect on crop phenological characteristics in this experiment, affecting nodes above the white flower (NAWF) on the main stem at 78 days after planting (DAP), 85 DAP (P<0.01) and 92 DAP (P<0.05) (Table 5.13). Plant population did not affect NAWF at 78 DAP (P>0.05) but did have a significant effect at 85 days (P<0.01) and 92 days (P<0.05). Neither plant population nor irrigation affected days after planting (DAP) to NAWF=5.
Table 5.13  Summary of ANOVA of plant population and irrigation frequency on phenological characteristics of the cultivar Iolatan 7 in the plant population x irrigation experiment at CRI, Turkmenistan in 2002

<table>
<thead>
<tr>
<th></th>
<th>First fruiting node</th>
<th>Square retention 65 DAP</th>
<th>Square retention 72 DAP</th>
<th>Squaring nodes per plant 65 DAP</th>
<th>No of FP1 sympodia per plant 72 DAP</th>
<th>NAWF&lt;sup&gt;1&lt;/sup&gt; 78 DAP</th>
<th>NAWF&lt;sup&gt;1&lt;/sup&gt; 85 DAP</th>
<th>NAWF&lt;sup&gt;1&lt;/sup&gt; 92 DAP</th>
<th>Change in NAWF&lt;sup&gt;1&lt;/sup&gt;/day (24 Days)</th>
<th>Node change from 78 DAP to NAWF&lt;sup&gt;1&lt;/sup&gt; =5</th>
<th>DAP to NAWF&lt;sup&gt;1&lt;/sup&gt; = 5</th>
<th>Plant height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>NS</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
<td>*</td>
<td>NS</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Irrigation</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
</tr>
<tr>
<td>frequency</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Interaction</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Significances **, * for P< 0.01; 0.01 < p < 0.05
NS – Not Significant (P≥0.05)
<sup>1</sup> nodes above the white flower

119
Number of sympodia per plant with first position squaring nodes were not statistically different for plant density or irrigation treatments when measured 65DAP but were for plant population (P<0.01) and irrigation frequency (P<0.05) when measured 72 DAP.

As plant populations increased numbers of FP1 sympodia per plant decreased (Table 5.14), as observed in the experiments reported in Turkmenistan by Bakasov and Yagmurov (1974) and also overseas in the experiments on plastochron reported by Buxton et al. (1977). As number of irrigations increased, the effect was the opposite, that is the numbers of FP1 sympodia per plant increased (see Table 5.15).

There was a significant interaction effect of population and irrigation on phenology only when measured at 78 DAP. This is reported in Figure 5.16. At all other times (days after planting) the effect of one factor on phenology can be reported (see Tables 5.14 and 5.15).

**Table 5.14**  Effect of plant population on plant phenology of the cultivar Iolatan 7 in the plant population x irrigation experiment at CRI, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>PP/ha (planted) ‘000</th>
<th>% Square retention 65 DAP</th>
<th>No of FP1 sympodia/ plant 72 DAP</th>
<th>NAWF * 85 DAP</th>
<th>NAWF * 92 DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>88.9</td>
<td>9.1</td>
<td>7.2</td>
<td>6.5</td>
</tr>
<tr>
<td>60</td>
<td>85.6</td>
<td>8.4</td>
<td>6.9</td>
<td>6.2</td>
</tr>
<tr>
<td>90</td>
<td>88.4</td>
<td>8.3</td>
<td>6.6</td>
<td>6.0</td>
</tr>
<tr>
<td>120</td>
<td>80.7</td>
<td>7.6</td>
<td>6.5</td>
<td>5.8</td>
</tr>
<tr>
<td>150</td>
<td>86.8</td>
<td>7.8</td>
<td>6.3</td>
<td>5.6</td>
</tr>
<tr>
<td>l.s.d (0.05)</td>
<td>7.2</td>
<td>0.8</td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*1 fruiting branches with first position fruiting bodies on each plant at 72 DAP

*2 nodes above the white flower
Table 5.15  Effect of irrigation frequency on phenology of the cultivar Iolatan 7 in the plant population x irrigation experiment at CRI, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Irrigation frequency</th>
<th>No of FP1 sympodia/plant 72 DAP</th>
<th>NAWF 78 DAP</th>
<th>NAWF 85 DAP</th>
<th>NAWF 92 DAP</th>
<th>Plant height 12.7.02</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>7.5</td>
<td>6.1</td>
<td>5.4</td>
<td>5.0</td>
<td>30.8</td>
</tr>
<tr>
<td>one</td>
<td>8.2</td>
<td>7.0</td>
<td>6.8</td>
<td>6.2</td>
<td>33.9</td>
</tr>
<tr>
<td>two</td>
<td>8.6</td>
<td>7.7</td>
<td>7.6</td>
<td>6.6</td>
<td>37.7</td>
</tr>
<tr>
<td>five</td>
<td>8.7</td>
<td>7.5</td>
<td>7.2</td>
<td>6.3</td>
<td>38.3</td>
</tr>
<tr>
<td>l.s.d. (0.05)</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
<td>0.9</td>
<td>3.1</td>
</tr>
</tbody>
</table>

1 fruiting branches with first position fruiting bodies on each plant at 72 DAP
2 nodes above the white flower

Table 5.16  Effect of interaction between population and irrigation on phenology of the cultivar Iolatan 7 at 78DAP in the plant population x irrigation experiment at CRI, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Number of irrigations</th>
<th>Sown plant population (plants/ha)</th>
<th>Final plant population (plants/ha)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>20,000</td>
<td>20,625</td>
<td>50,417</td>
<td>77,361</td>
</tr>
<tr>
<td>50,000</td>
<td>89,097</td>
<td>112,222</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NAWF 78 DAP</th>
<th>6.1</th>
<th>6.2</th>
<th>6.1</th>
<th>6.5</th>
<th>5.6</th>
<th>6.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.2</td>
<td>7.2</td>
<td>6.6</td>
<td>6.9</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td>2</td>
<td>8.1</td>
<td>7.7</td>
<td>7.6</td>
<td>7.5</td>
<td>7.4</td>
<td>7.7</td>
</tr>
<tr>
<td>5</td>
<td>7.8</td>
<td>7.7</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.5</td>
</tr>
<tr>
<td>Mean</td>
<td>7.3</td>
<td>7.2</td>
<td>6.9</td>
<td>7.0</td>
<td>6.9</td>
<td></td>
</tr>
</tbody>
</table>

3 nodes above the white flower; L.s.d. (0.05) for irrigation treatments = 0.6

Although there were considerable numerical differences between plant population treatments for DAP to NAWF=5 (140, 123, 117, 111 and 114 DAP for 20, 50, 80, 110 and 150,000 p/ha) there were no statistically significance differences between plant population treatments in DAP to NAWF=5 or ‘cut-out’. Nor was there a statistical difference between irrigation frequency treatments for DAP to NAWF=5. Therefore no significant effect of either factor on
physiological cutout could be proven from this experiment and COTMAN curves could not be used to characterize phenological differences observed due to population in this experiment.

As these data were extracted from recordings made by scientists at the CRI, Iolatan, who were novices at the use of the COTMAN system, the phenological recordings made in this experiment could be repeated with profit in another similar experiment.

The average rate of change of NAWF over time could be calculated from the data. The average rate of descent of the NAWF ‘curve’ was 0.076 nodes per day compared to 0.173 nodes per day for the cultivar Turkmenbashi 1 recorded at ARPEC and 0.213 nodes per day in the COTMAN ‘target development curve’ based on data from Arkansas, USA (Oosterhuis et al., 1996b). Although no direct comparison could be made, as sites were different in planting date, accumulated heat units during the season and fertilizer practice, this data may indicate that the cultivar Iolatan 7 is later maturing than Turkmenbashi 1. This is in accordance with the observations of foreign cotton breeders that Turkmenbashi 1 is ‘cutting out’ too early in the season and may have taken the trend of Turkmen breeders to introduce early maturity into their cultivars too far (Professor S. Gallanopolou-Seneca, Thessaly University, Greece, pers. comm. 2002). Lower rates of descent of NAWF suggests less boll load relative to the vegetative capacity of the plant. This may be due to delayed fruit initiation, poor fruit set or slow fruiting development (Oosterhuis et al., 1996b).

The average rate of descent of the NAWF ‘curve’ may be used to characterize cotton cultivars in Turkmenistan in the same way that Jackson and Arkin (1982) used the constant $a_1^{1/2}$, termed the fruiting site production rate, (FSPR) in the function:
dSITE/dtp=(a \_1 \ast SITE)^{\frac{1}{2}} \quad \text{(where SITE is the number of fruiting sites, tp is physiological time as accumulated heat units and a \_1 is a constant)}

to characterize early maturing and late maturing cotton cultivars. Values of FSPR ranged from 0.0154 for the early maturing \textit{G. hirsutum} cultivar Cascot C13 to 0.0125 for the relatively late maturing \textit{G. hirsutum} Acala SJ-2 (Jackson and Arkin, 1982).

No effect on the number of the first fruiting node was made by either population or irrigation in this experiment. Average first fruiting node recorded was 6.4. This result is contrary to the results obtained by Bakasov and Yagmorov (1974) in their experiment in Turkmenistan (FFN decreased from 5.7-5.0 when plant density increased from 100-200,000 plants/ha for the cultivar 9647E and 6.5-5.4 in the same population range for cultivar 9301E) and FFN also decreased with increased population in the experiment reported by Kerby \textit{et al}. (1990a). Square retention was affected by plant density (P<0.05) when measured on 29/6/02 or 65 DAP (88.9\% at 20,000 p/ha vs. 80.7\% at 110,000 p/ha) but not affected by irrigation frequency at this time. Retention was not affected by either plant density or irrigation frequency when measured on 6/7/02 (72 DAP).

In general, plant population and irrigation number had opposing effects on phenological development of the Iolatan 7 cultivar in this experiment.
5.4 General discussion

The optimum plant populations for the modern Turkmen short staple cultivars Turkmenbashi 1 and Iolatan 7 are shown in Table 5.17. These populations are around 100,000 plants/ha (the $R^2$ value are too low to give the optimum except in approximate terms). In this regard, the field populations measured in the survey reported in Chapter 4 are only around one half of the optimum.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Location</th>
<th>Cultivar</th>
<th>Optimum final population treatment plants/ha</th>
<th>Optimum population from regression equations</th>
<th>$R^2$</th>
<th>% increase in fibre$^1$</th>
<th>% increase in fibre$^2$</th>
<th>% increase in seed cotton$^1$</th>
<th>% increase in seed cotton$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant pop x gap</td>
<td>ARPEC</td>
<td>Tb1</td>
<td>101,000</td>
<td>100,000</td>
<td>0.38/0.36</td>
<td>25</td>
<td>9</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>Plant pop x gap</td>
<td>CRI</td>
<td>I7$^4$</td>
<td>105,000</td>
<td>100,000</td>
<td>0.66</td>
<td>NA</td>
<td>NA</td>
<td>77</td>
<td>51</td>
</tr>
<tr>
<td>Irrigation x pp</td>
<td>CRI</td>
<td>Iolatan</td>
<td>77,000</td>
<td>100,000</td>
<td>0.51</td>
<td>NA</td>
<td>NA</td>
<td>32</td>
<td>16</td>
</tr>
</tbody>
</table>

$^1$ Based on yield differences between those at 50-55,000 p/ha and optimum treatments. Plant populations of under 55,000 plants/ha occurred in sixteen of the twenty fields surveyed in 2001.

$^2$ Based on the above x regression coefficient established in the experiments concerned

3 Turkmenbashi 1
4 Iolatan 7

$^5 R^2 = 0.38$ for seed cotton; 0.36 for fibre

The experiments reported in this Chapter indicate that the response of the new generation of Turkmen short staple cultivars is similar to the old (Kudratullaev, 1981; Kudratullaev et al., 1981).

Gaps in the field up to four 50 cm gaps in a 10 m row had no significant effect on the parameters of yield measured in two experiments. This indicates that, up to a level of four 50-
centimeter gaps in each 10 meter row or 20% gaps, low and variable yields measured in the field survey were not due to gaps in the fields. As increasing the number of 50-centimeter gaps up to four caused an arithmetic tendency to decreased yields in both experiments (see Table 5.1, 5.6), further experiments with a greater number of spaces (say up to 8 x 50 cm gaps in each 10 meters of row or 40% gaps) are indicated. There was no interaction of plant population and gaps in affecting yield, maturity or any other characteristic in this experiment.

There was a significant interaction between plant population and irrigation for the yield component boll weight (P<0.01). This result supports, in part, the hypothesis developed from the field survey (Chapter 4) that in poorly managed/irrigated fields there may be negative interactions between plant population and yield and yield components. This may indicate that where irrigation (or other inputs crucial to good management like fertilizers) is in short supply, farmers may have learned to adjust plant populations so as not to decrease yield components and yields.

The lack of a plant population x irrigation interaction is an important one. In the literature there may be no reported interaction in yield response between plant population and irrigation, possibly due to the beneficial effect of higher water levels being cancelled by leaching of nitrogen (Bruyn et al., 1989). However, in the experiment reported at CRI, movement of water between plots was probably responsible for the lack of interaction. Further population x irrigation experiments in which greater control over movement of water in plots can be exercised, and in which experienced personnel can make phenological measurements, would be valuable.
The effect of population on yield was high (74% fibre, 62% seed cotton when yields of the lowest and optimum treatments are considered). This is larger than the 10-15% reported in local literature (Bakasov, 1977; Bakasov and Yagmurov, 1974; Bakasov et al., 1976; Kudratullaev, 1981; Kudratullaev et al., 1981) and higher than that reported in the literature when calculated on the same basis (an increase of from 6-7% reported in Heitholt, 1994 to 42% in Anastassiou-Lefkopoulou and Sotiriadis, 1984). The reason for this difference with the local literature is partly due to ‘control’ plant populations in local experiments being generally 100,000 plants/ha, or around the populations that have been found optimal in the experiments reported above, compared to control populations used in the experiments reported here equivalent to the lowest found in surveyed fields.

Another reason for the large increases in yield reported above may be explained by the use of small stature cultivars in the experiments (Bilbro, 1972; Verhalen and Williams, 1992) growing in the short season conditions prevailing in Turkmenistan. (See Chapter 3 for details of heat units per season at the two sites.) Ashgabat/Anau and other areas in Turkmenistan (crop in the field around 150-155 days) would be regarded as ‘short-season’ by Australian standards (crop in the field 180-190 days) and comparable to areas like Arkansas in the USA and Greece in Europe (Professor S. Galanopolou-Seneca, pers. comm. 2002).

The parabolic nature of the responses for Turkmenbashi 1 (see Figs 5.1 and 5.2) agree with the experiments of Bridge et al. (1973), Gutstein (1973) and Larson et al. (1996) that concluded that an early growth termination during the growing season in cotton leads in most instances to a parabolic yield response with a finite optimum plant density. An asymptotic curve fitted to the data for the population x gap experiment at CRI with no loss in regression adds support to the
proposition that Iolatan 7 may be classed as a ‘long season’ cultivar (Gutstein, 1973) growing in a short season environment.

Constable (1997) gives an asymptote as the typical long-term response to plant density for conventional *G. hirsutum* cultivars in Australia. However, new genetically modified cultivars with low insect attack and ‘tipping out’ may have a more parabolic response curve (J. Marshall, Cotton Seed Distributors, Narrabri, unpublished data 2002; G. Constable, Cotton Research Institute Narrabri, pers. comm. 2003). The geometry of the cotton plant growing in Turkmenistan under conditions of almost no insect attack (low ‘tipping-out’ or production of lateral branches) closely resembles that of cotton genetically modified for insect resistance grown in Australia (G. Constable, CRI, Narrabri, pers. comm. 2003). The large responses recorded in this thesis may therefore be in part explained by the crop geometry of the Turkmen cultivars growing under conditions of low insect attack.

In all experiments decreases in fruit production per plant were noted with increasing plant population but the greater number of plants resulted in an over-all increase in fruit production and yield per unit area. These results were in accord with the literature (Jones and Wells, 1997; Hoskinson *et al.*, 1972; Mass, 1997; Wanjura and Bilbro, 1977; Anastassiou-Lefkopoulou and Sotiriadis, 1984).

Increasing plant population had little effect on fibre properties at ARPEC other than small effects on micronaire and upper half mean length. Neither of these changes would have affected fibre quality to the extent of a change in economic grade of the cotton produced.
Increasing plant density advanced crop maturity, both in measures like green bolls at maturity (at ARPEC and CRI) and as reduced days after planting to ‘cut-out’ as characterized by NAWF=5 at ARPEC. These results agree with the results reported by Buxton et al. (1977) and generally agree with the effects on maturity reported above (that is increased plant population promotes crop maturity). Early maturity is a positive characteristic in cotton (Galanopoulou - Sendouca, 2002).

As plant population affected the number of days after planting to NAWF=5 for Turkmenbashi 1 at ARPEC, plant population treatment differences may be characterized by COTMAN curves for each treatment. This is done in Chapter 8. Although there were considerable numerical differences between plant population treatments for DAP to NAWF=5 in the population x irrigation experiment at CRI, there was no significance statistical differences between plant population treatments in DAP to NAWF=5 or ‘cut-out’ for the cultivar Iolatan 7. Nor was there a statistical difference between irrigation treatments for DAP to NAWF=5. Therefore no significant effect of either factor on physiological cutout could be proven from this experiment and COTMAN curves could not be used to characterize phenological differences observed in this experiment.

From comparison of the plant population optima found from the experiments reported in this Chapter compared to those found in the field surveys reported in Chapter 4, it would seem there would be a considerable production advantage in seed cotton and fibre yields from increasing field plant populations in Turkmenistan. This could be done with no economic penalty for fibre quality.
The reasons for low field plant populations are investigated in Chapter 6. The implications of the relationship between plant populations and phenology will be considered in Chapter 8.
CHAPTER 6 REASONS FOR LOW PLANT POPULATIONS IN COTTON FIELDS IN TURKMENISTAN

6.1 Introduction

The relationship between plant population and yield of cotton has been investigated in Turkmenistan over many years (Kudratullaev et al., 1981). These studies indicated that plant populations of 10-11 plants/m² gave maximum yields, although this may increase to 18 plants/m² for long staple cultivars under certain conditions (Kudratullaev, 1981). The results of the ‘population x gap’ and ‘population x irrigation’ experiments conducted with G. hirsutum cultivars Turkmenbashi 1 and Iolatan 7 at ARPEC and CRI, reported in Chapter 5, are in accord with these prior findings. It would seem that the response of the newer generation of Turkmen G. hirsutum cotton cultivars to plant population is similar to that of the older.

In Chapter 4 of this thesis, plant populations were reported to be 2-6 plants/m² on both government farms and in farmer’s fields in Ahal Velayat. Such low populations may severely reduce yields, so investigation of the reasons for low populations is warranted.

Plant populations in cotton crops may be reduced shortly after planting by many factors including salinity, high soil bulk density, poor drainage and disease (Johnson et al., 1974; TACIS, 1997). Strategies like late planting are used in some cotton areas to reduce the effect of diseases such as Alternaria blight (Padaganur et al., 1988). However, in most cotton areas of the world seed dressings are applied before planting to protect the young cotton plant from a range of potentially damaging seed-borne diseases (Munro, 1987). In-furrow fungicides are widely used in conventional tillage systems to reduce seedling mortality
caused by fungi (Colyer et al., 1987; Minton, 1986). The insecticide Aldicarb (2-methyl-2-methylthiopropanol) is often applied with fungicides to control early season insects and nematodes that affect seedling vigor and diseases (Colyer et al., 1987; Minton, 1986).

The practice of hand-thinning cotton fields is unheard of in most mechanized cotton producing countries, yet it is still common practice in the CIS (TACIS, 2002; Trives and Vaughan, 1998a). Seed is planted to excess to provide pre-thinning populations of 300,000 plants/ha, and plants are then hand-thinned to the target populations using the traditional Turkmen hoe. The reason given for this practice is that the combined energy of germination of a large number of seedlings is needed to break the soil crust that is formed in some years by early rain immediately following planting (Trives and Vaughan, 1998a). In the Central Asian republics, such hand thinning may also be a cause of substantial unintended cotton seedling losses. Research by Turkmen scientists has concentrated on the effect of thinning at various stages of seedling development where populations are kept at optimal levels of 8-10 plants/m² (Babaev, 2000), but it has not examined how hand thinning may result in unintended effects on populations.

This Chapter examines the effects of soil-borne fungal pathogens, insects and hand thinning on plant populations. In the experiments conducted at ARPEC in 2002 all plots were pre-irrigated, allowing salting to be eliminated as a factor causing low populations through early seedling deaths (Rejepov et al., 1991). Similarly, all plots were deep ploughed to 40 cm, so that the effect on plant growth of high soil bulk density could also be eliminated as a factor in the experiments (Avtonomov and Blijina, 1968; Batekaev et al., 1984; Rejepov et al., 1991; Sergaziev, 1977; TACIS, 1997; TACIS, 2001). Seed was acid de-linted before planting to eliminate seed-borne diseases. Thus, the effects of soil-borne fungal pathogens and insects, and the effect of thinning in reducing field plant populations shortly after
planting, could be examined in the experiments reported below, without confounding by salt
effects, seed-borne pathogens, or soil strength.

6.2 Materials and methods

6.2.1 Seedling death experiment at ARPEC

This experiment was designed so that any treatment effects on plant population could be
accounted for by seedling death or disease caused by specific fungal organisms or insect
pests. Treatments (T1 to T6) in this trial were seed-applied chemicals specific in protecting
the plant against the soil borne fungal disease *Rhizoctonia solani* (Keuhn)
(pentachloronitrobenzene or ‘pcnb’ – T2); against the soil borne fungal diseases *Pythium*
spp. and *Phytophthora* spp. (metalaxyl – T3); against the soil borne fungal diseases
*Rhizoctonia solani* (Kühn), *Pythium* spp. and *Phytophthora* spp. (metalaxyl + pcnb – T4)
and against early insect attack from thrips (*Thrips tabaci*) and aphids (*Smynthurodes betae*)
(imidacloprid – T5). A control treatment (T1) had no seed chemical treatment and one
treatment (T6) combined all treatments (pcnb + metalaxyl + imidacloprid).

Section 3.4 describes experimental site preparation.

After acid de-linting with small quantities of sulfuric acid to destroy seed-borne pathogen,
seed of 96% germination were dressed with the fungicide / insecticide combinations above
and 7 g/kg absorbent added as ‘binder’. Planting took place on 18/04/02 after a pre-plant
irrigation on 01/04/02. The sowing rate was intended to give an emerged plant density of
around 300,000 plants/ha, which is the pre-thinning target for the region. Hand thinning to a
population of 100,000 plants/ha was carried out on 6/05/02. The fertilizer applied was 18
kg/ha phosphorus (P) as super-phosphate incorporated pre-planting and before pre-plant irrigation, and 200 kg/ha nitrogen (N) as ammonium nitrate (Regipov et al., 1985) in a banded application 10 cm from the plant row, applied by hand on 5/6/02. After the pre-planting irrigation, five further furrow irrigations were carried out on 6/6/02, 6/7/02, 20/7/02, 7/8/02 and 24/8/02. Irrigation timings were based on the FAO ‘CROPWAT’ computer program (FAO, 1988) using meteorological data for Anau. Each irrigation provided approximately 1 ML/ha.

Hand-weeding of all plots was conducted 30/4/02 - 3/5/02, 21-24/5/02 and 14-17/6/02. Shielded spraying with Gramoxone (350 mg/l a.i.) was carried out using a knapsack spray on 21/6/02, 25-28/6/02, 4/7/02 and 15-17/7/02.

Plant counts of all rows in all plots were made on 17-18/5/02 and 11-13/6/02. Field (‘wet’) weights of a two-meter row of plants in the third row of each plot were determined on 14/6/02 by pulling up plants, carefully washing soil from roots and weighing. Visual assessment of presence or absence of insect damage was made 17-18/5/02 using a scale of low (1) to high (3) damage of cotyledons and new leaves. Assessment of presence of fungal damage due to Pythium spp., Phytophthora spp. or Rhizoctonia solani (Keuhn) was made by visual examination of plant roots and stems in a two-meter length of plants from the first row of each plot and assessing plants on appearance compared to illustrations and descriptions in standard texts (Hodges, 1992; N.S.W.D.A., 1991). Final yields were assessed 18/9/02 and fiber quality, GOT and 100 seed weights according to the procedures outlined in Chapter 3. Maturity on the basis of the percentage of open bolls was calculated from records of 10 plants in each third row taken 23/8/02, 2/9/02 and 10/9/02.
6.2.2 Effect of kind of hoe and desired plant population on plant population experiment at ARPEC

The factors investigated were two types of thinning hoe; the ‘Turkmen’ combination hoe-shovel and the Russian or ‘Dutch’ type hoe used in Europe / USA; which were used to try and achieve two ‘target’ plant populations of 6 and 10 plants/m$^2$ of the cultivar Turkmenbashi 1. The two types of hoe are shown in Figure 6.1.

![Figure 6.1 Turkmen hoe (left) and Russian hoe (right) used in effect of kind of hoe and desired plant density on plant population at ARPEC, Turkmenistan in 2002](image)

The design was a 2 x 2 factorial as a Randomized Complete Block. Plot size was one row (90 cm spacing) x 10 m for each treatment with five replicates. An elite seed field planted with Turkmenbashi 1 was used for the experiment; the field was planted by tractor using fuzzy seed (as with commercial practice) to give a plant population of around 32 plants/m$^2$ (counted on 13/5/2002) and marked plots were thinned on 14/5/2002 using the two types of hoe, aiming to give desired plant populations of 6 and 10 plants/m$^2$.

Operators were shown plantings at the two treatment plant populations in nearby experimental fields and allowed to inspect and measure inter-plant spacing in the rows for as long as needed to gain a satisfactory knowledge of these. Generally each operator needed 10 minutes to declare themselves conversant with the required populations. The five
operators used in the experiment were the best selected after observing a large group of 37 at work in an adjoining seed production field during the week prior to the experiment (the target plant population in this field was 100,000 plants/ha) on the basis of speed and thoroughness. Plants in each 10-metre row were counted on 14/5/02 immediately after thinning. Both the plant numbers per row and per hectare and the absolute value of differences between actual and target plant populations per row were recorded. Statistical analysis was carried out on the data for absolute value of differences between actual and target plant populations per row.

6.2.3 Effect of operator on thinned field populations of elite seed field at ARPEC

This experiment investigated the effect of operator on the plant populations arrived at by thinning an elite seed field planted with Turkmenbashi 1. The design was a Randomised Complete Block with each operator’s work being a ‘treatment’ and with four replicates of each (each of 20 operators thinned four randomly allocated rows across the field). Treatment rows were 10 m long and spaced at 90 cm.

An elite seed field planted with Turkmenbashi 1 was used for the experiment. The field was planted by tractor using fuzzy seed to give a plant population of around 32 plants/m² (counted on 13/5/2002), and marked plots were thinned on 20/5/2002 to a target population of 100,000 plants/ha.

Land preparation of the experimental site was as described in Section 6.2.1.
6.2.4 Effect of operator on thinned field populations of elite seed field at ‘Watan’ field at the Nine Commissars Cooperative in Ahal Velayat

This was a further experiment to investigate the effect of operator on the plant populations arrived at by thinning a commercial cotton field planted with Turkmenbashi 1. The design was a Randomised Complete Block with each operator’s work being a ‘treatment’ and with four replicates of each (each of 18 operators thinned four randomly allocated rows across the field). Treatment rows were 10m long and spaced at 90 cm. The field was planted by tractor using fuzzy seed to give a plant population of around 32 plants/m² (counted on 31/5/2002), and marked plots were thinned on 31/5/2002 to a target population of 100,000 plants/ha.

6.3 Results and discussion

6.3.1 Seedling death trial at ARPEC

No significant differences in plant populations between treatments were recorded in plant counts taken on 17-18/5/2002 and 11-13/6/2002 (one and two months after planting). Differences in treatment means were large in this experiment (particularly for treatments T5 and T6 that included the insecticide imidaclorpid) but not statistically significant (Table 6.1). The size of the arithmetic differences in the two treatments that included insecticide (5 and 6) indicates that the experiment should be repeated with greater control over error and over a period of years that may differ in the intensity of insect attack.
Table 6.1 Effect of seed treatment on plant population (plants/ha) at ARPEC, Turkmenistan on two occasions (17-18/5/2002, 11-13/6/2002).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Date of counting</th>
<th>Date of counting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Control</td>
<td>82,407</td>
<td>80,000</td>
</tr>
<tr>
<td>2 pcnb (pentachloronitrobenzene)</td>
<td>80,093</td>
<td>80,000</td>
</tr>
<tr>
<td>3 metalaxyl</td>
<td>81,944</td>
<td>79,444</td>
</tr>
<tr>
<td>4 metalaxyl + pcnb</td>
<td>86,111</td>
<td>81,389</td>
</tr>
<tr>
<td>5 imidacloprid</td>
<td>97,222</td>
<td>100,833</td>
</tr>
<tr>
<td>6 pcnb + metalaxyl + imidacloprid</td>
<td>95,833 ¹</td>
<td>98,611</td>
</tr>
<tr>
<td>Mean</td>
<td>87,269 ¹</td>
<td>86,713 ¹</td>
</tr>
</tbody>
</table>

¹ The treatment effects were not statistically significant (P>0.05) at either time of counting.

There was no significant difference in visual scores of *Pythium* or *Phytophthora* or *Rhizoctonia* damage when assessed on 17-18 May 2002.

There was a significant difference in insect attack (bean aphid, *Smynthurodes betae*) when visually assessed on 17-18 May, 2002 (Figure 6.2). This is a further indicator that early insect attack may be a factor limiting plant populations under certain conditions, and that this experiment could profitably be repeated.
Figure 6.2 Effect of seed treatments 1-6 on visually assessed insect damage in cotton seedlings at ARPEC, Turkmenistan (17-18/5/2002) (l.s.d (0.05) = 0.48)

The effect of seed treatment on plant weight per 2-m length of row, measured on 11-13/6/2002, was significant (P<0.05) (Figure 6.3). On a per plant basis, however, the weights were not significantly different (P≥0.05).

Figure 6.3 Effect of seed treatments 1-6 on plant wet weights of cotton seedlings at ARPEC, Turkmenistan (17-18/5/2002) (l.s.d (0.05) = 0.27)
Some researchers have reported that non-lethal infection of cotton seedlings can result in stunting, delayed fruiting and reduced yields (Colyer and Vernon, 1993; Batson, 1982; Roncardori et al., 1968). However, it has also been established that early seedling losses may not have a significant effect on final yield if the surviving populations are near the optimum (Holman and Oosterhuis, 1999; Longer and Oosterhuis, 1999). This was the case in this experiment, in which the surviving population in all treatments exceeded 80,000 plants/ha and there was no significant effect on final yield (average of all treatments 2,919 kg/ha seed cotton), fibre quality (average of all treatments 4.7 micronaire, 0.88 ML, 1.10 UHML, 80.3 UI, 19.0 SFI, Pressley strength 7.97, GOT 38.7, 100 seed weight 10.1 g) or maturity (open bolls 18.6%, 53.0% and 80.1% 130 DAP, 140 DAP and 148DAP).

The acid used to de-lint the experimental seed to exclude seed-borne diseases as a confounding factor in this experiment may have eliminated some potential soil-borne seedling diseases (MacDonald et al., 1947) and affected results. In future experiments of this kind heat-treated fuzzy seed could be used, which may eliminate seed-borne pathogens without having an effect on soil-borne ones.

6.3.2 Effect of kind of hoe and desired or ‘target’ plant density on plant populations trial at ARPEC, Anau

There was no significant difference between using a traditional Turkmen hoe and a ‘Russian’ or ‘Dutch’ hoe to thin young cotton seedlings (Table 6.2). However, there was a significant difference in achieving target populations between thinning to lower plant populations (60,000 plants/ha) and higher plant populations (100,000 plants/ha). Operators found it difficult in this experiment to achieve a plant population of 10 plants/m² (100,000 plants/ha). They achieved 82,000 plants/ha using the Turkmen hoe and 86,000 plants/ha...
using the ‘Russian’ hoe. They found it much easier to achieve the lower plant density of 6 plants/m² (60,000 plants/ha). They achieved 62,000 plants/ha with the Turkmen hoe and 59,000 plants/ha with the ‘Russian’ hoe. Initial plant populations in this trial were 320,000 plants per ha. The results in Table 6.2 show the differences between targeted and actual numbers of counted seedlings in a 10 m row when thinned by the two kinds of hoes.

**Table 6.2**  Effect of hoe type and target plant population on the difference between actual and target seedling numbers per 10-m length of row (thinned on 14/5/2002)

<table>
<thead>
<tr>
<th>Target population</th>
<th>60,000 p/ha</th>
<th>100,000 p/ha</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkmen hoe</td>
<td>3</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Russian hoe</td>
<td>5</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>Average</td>
<td>4</td>
<td>15 ¹</td>
<td></td>
</tr>
</tbody>
</table>

L.S.D. (0.05) = 6, L.S.D. (0.01) = 8

¹ Significant difference for difference in number of plants in a 10 m row length

This is a significant experimental result, in that it may explain the field plant populations observed in late May – early June throughout Turkmenistan and documented in Chapter 4.

The Central Asian system is to hand thin after mechanical planting. Operators find it difficult to thin to optimum plant populations of around 10 plants/m² as neither the Turkmen nor the Russian hoe can be wielded with the dexterity to allow the very small inter-plant distances that are equivalent to populations of 10 plants/m² in the traditional 90 cm row configuration. It should be noted, however, that at a 60 cm row configuration the inter-plant spacing in the row is the equivalent of 6 plants/m² in a 90 cm row configuration (see Chapter 7 for a fuller discussion of this) and therefore competent operators would, on the basis of the experimental results above, be able to thin to close to the optimum plant population of 10 plants/m² in a 60 cm row configuration.
The operators selected for this experiment were the five most competent and dexterous of 37 operators. They had also spent a week working in a seed production field next to the experimental area where the target population was 100,000 plants/ha. When they were also asked to thin two 50 m rows each before the experiment started, but after they had worked in the seed production field for a week, they achieved an average plant population of 78,000 plants/ha. When large sections of the population are mobilized to thin the fields (as they are by the Government of Turkmenistan in April-May of each season) many operators would be expected to fall short of the standards of proficiency shown by the five operators in this trial. The experiment described below was an attempt to assess the variability of operators to thin plants during the annual periods of mass mobilization of personnel to thin fields that takes place in Turkmenistan.

6.3.3 Effect of operator on plant density in an elite seed field at ARPEC

A significant variation (P<0.05) was observed in plant populations achieved by the 20 operators in this experiment (Figure 6.4 below).

![Figure 6.4](image)

**Figure 6.4** Effect of operator on thinned plant populations (plants/m²) (l.s.d. (0.05) = 3.3)
Average plant populations achieved were quite high (average 8.5 plants/m$^2$; ± 2.3 plants/m$^2$), as in this field all operators were required to thin to 10 plants/m$^2$ (from an original plant population of 32 plants/m$^2$) and could inspect an experimental stand of 10 plants/m$^2$ (100,000 plants/ha) as a standard. This training is not common practice in Turkmenistan. As reported above, few operators could thin to 10 plants/m$^2$.

When operators are widely mobilized, rather than being selected specifically for this work, the fields they thin may be highly variable in plant population, as well as below the optimum. This conclusion is supported by the high variability of plant population (sensitivity coefficient of 29.9%) reported in the field survey (Chapter 4).

### 6.3.4 Effect of operator on thinned field populations in ‘Watan’ field at the Nine Commissars Cooperative in Ahal Velayat

A measurement of two thinned field plant populations taken in the ‘Watan’ field at the Nine Commissars Cooperative in Ahal Velayat on 31/5/2002, illustrates that when operators are widely mobilized, the fields they thin may be highly variable in plant population, as well as below the optimum. In the first field, five of a group of 18 operators thinned to 60,000 plants/ha or less and only 6 thinned to plant populations over 100,000 plants/ha (see Figure 6.5 below). In the second field only one operator of a group of ten thinned to above 100,000 plants/ha.
Recent reviews produced in Australia on the causes of early seedling death have concentrated on fungal diseases like Black root rot (Nehl, 2001), *Verticillium* and *Fusarium* wilt (Nehl and Allen, 2001) and insect pests (Nehl, 2001) and their effects on field plant populations. Other recent comprehensive reviews that include experience from a number of cotton producing countries also emphasize the importance of insect (Matthews and Tunstall, 1994) and insect and fungal pests (Kirkpatrick and Rothrock, 2001; Asian Development Bank, 2004) in early seedling death of cotton.

In the experiment reported in Section 6.3.1, there was no significant effect on plant populations of seed treatments against fungal and insect pathogens. Therefore, the large discrepancies between planted seedling populations (300,000-400,000p/ha) and those existing at the start of June in experimental and commercial fields can be explained by hand thinning that is carried out after planting by machine in May throughout Turkmenistan and other CIS countries.

**Figure 6.5** Distribution of thinned plant populations (plants/m$^2$) for 18 operators in the Nine Commissars Cooperative Farm, Turkmenistan, counted on 31/5/2002.
In many years, cotton field insect pest populations early in the season will be unusually low compared to the populations that may be expected in many cotton-producing countries (Matthews, 2001). This is due to the desert conditions in which cotton is grown in Turkmenistan; the absence of crops and pastures in current Turkmen rotations for insect pests to over-winter in; and to the use of biological control of cotton pests (the egg parasitoid *Habrobracon* in Turkmenistan reared on the cereal pest, *Ephestia elutella*) that was initiated some 20-25 years ago following many reports of insecticide poisoning in Central Asia (Matthews, 2001).

However, in certain years, there may be an abundance of early season insect pests that may reduce plant population in cotton fields. In these years, there is a possibility that seed treatments, especially against insect pests like bean aphid, may be able to reduce early seedling deaths and therefore increase field cotton plant populations (Matthews, 2001). For example, in Surkhandarya, Uzbekistan in 2000, egg parasitoid *Trichogramma* (used in place of *Habrobracon*) was not effective, due to the bio-factory not following the rearing instructions fully. In this situation early season spraying to control insect pests reduced early seedling deaths and substantially increased field plant populations and yields (Dr. M. Armitage, Asian Development Bank Office, Tashkent, pers. comm. 2001).

It should also be noted that early season spraying could reduce numbers of beneficial insects like *Coccinellids* and lacewings (Asian Development Bank, 2004). Therefore seed treatment with insecticides like imidacloprid is preferable to spraying to control early season insect pests.

In contrast to attack by insects and plant pathogens, hand thinning shortly after planting had a significant effect in lowering field plant populations in experimental fields to levels below
those established in this thesis and previously in Turkmenistan as being optimal for seed cotton and fiber yields. Moreover, there was significant variation in populations in experiments conducted on operators at the Nine Commissars Co-operative in Ahal Velayat.

6.4 Conclusion

To conclude, the current system of planting untreated fuzzy seed at high rates and then thinning using hand held implements used in Turkmenistan produces plant populations that are well below those optimal for seed cotton and fiber production.
CHAPTER 7  YIELD, MATURITY AND QUALITY RESPONSES TO 
IRRIGATION NUMBER AND ROW SPACING

7.1 Introduction

The field survey results reported in Chapter 4 showed a weak but overall positive effect of population on yield. In low-yielding fields, factors other than population may restrict yield, in which case the low populations recorded may be adequate unless other constraints to yield are addressed. In higher yielding or well-managed fields, increases in plant populations did not lead to reduced boll weights or boll numbers per plant. These results indicate that increasing plant populations in well-managed fields could produce yield increases. The management factor regarded as most important in Turkmenistan in determining cotton yields is irrigation (Regepov et al., 1985; TACIS 1999). Thus the survey results could be interpreted to suggest that under-irrigation is one possible cause of low yields in Turkmenistan, even though irrigation is regulated by the State and in theory there should be no water limitation.

A plant population x irrigation trial was therefore carried out in 2002 to test for any interaction between population and irrigation frequency (Chapter 5). The interaction between these two factors was not significant (P>0.05) for yield, but was for the yield component boll weight (P<0.01). This result supports, in part, the hypothesis developed from the field survey (Chapter 4) that in poorly-managed/irrigated fields there may be a negative correlation between plant population and yield and yield components.

An unexpected side-result of the plant population x irrigation experiment was the finding of no significant response to more than a single irrigation, although five irrigations are used in the region. On the basis of this experiment, it would seem unlikely that under-irrigation was
the unidentified constraint to yield in the lower-yielding fields. However, there were practical difficulties in managing the irrigation in this experiment, thus justifying further investigation of this factor.

Extensive experiments in Turkmenistan in the 1970s, across a number of regions (Rejepov and Kudratullaev, 1979), reached the conclusion that 6 irrigations with a total of around 5.0-5.5 ML/ha was required for optimum yields, except in very short season conditions where 4 irrigations with 4.2 ML/ha was required. The experiments were conducted in the heyday of Soviet cotton cultivation in Central Asia when water was relatively abundant. They were designed with the lowest number of irrigations in each experiment being close to the optimum in the particular area. In the 21st century agricultural context of Turkmenistan, dominated by the struggle for riparian rights in Central Asia and salting due to an increasingly high water table, there is a need to re-examine cotton water requirements.

The first experiment reported in this chapter further examined response to the number of irrigations. Detailed phenological observations in the experiment in Chapter 5 showed significant responses to irrigation frequency. As target development curves generated by the COTMAN crop monitoring system are particularly responsive to drought (Bourland et al., 1997b) the experiment with irrigation was used to test the utility of the COTMAN system under Turkmen conditions.

The second experiment reported in this chapter concerned the interaction between row spacing, genotype and population. Interactions between genotype and plant population, and between row spacing and plant population have all been reported in the literature (see Chapter 2). These interactions were examined under Turkmen conditions. The superiority of narrower than conventional rows is more evident when the prevailing conditions prohibit
canopy closure by mid-July in conventional rows in short season environments (Galanopoulou-Sendouca et al., 1980). Such conditions apply in many years in Turkmenistan. Therefore, the study of effect of row spacing on yield of cotton is an important complement to the study of plant populations on yield in that country. Outside Turkmenistan, narrow rows are expected to become more frequent with the use of low nutrient demanding, short growth cotton cultivars and the use of low input or ‘organic’ cotton growing systems (Galanopoulou-Sendouca, 1998).

Differences in yield in row spacing experiments may be simply attributed to less competition within rows at the same plant population for the narrower row spacing, rather than for greater light interception at differing row spaces (Boquet and Coco, 1993). There were reports in the 2001 (Ministry of Agriculture, Turkmenistan, 2001) and 2002 crop seasons (J. Yagmur, Deputy Director, CRI, Iolatan, pers. comm. 2002) that many farmers in the Lebap and Mary Velayats of Turkmenistan had come to this conclusion and were increasing plant populations in their fields by using the same within-the-row spacing but using 60 or 70 cm rather than 90 cm rows. The experiment reported in this thesis therefore use row spacing with plant intervals adjusted within the row so that plant populations are the same for different row spacing treatments.

Because of potential effects of irrigation and row spacing on fibre quality and maturity (Bruyn et al., 1989; Kharche, 1984), effects on these characteristics were also measured in both experiments.

7.2 Materials and methods
7.2.1 Number of irrigations experiment at ARPEC

After pre-planting irrigation, one, two, three or five irrigations were applied on 6/6/02, 6/7/02, 20/7/02, 7/8/02 and 24/8/02 (treatment 1 received one irrigation on 6/6/02; treatment 2 received two irrigations on 6/6/02 and 6/7/02; treatment 3 received three irrigations on 6/6/02, 6/7/02 and 20/7/02; and treatment 4 received 5 irrigations on 6/6/02, 6/7/02, 20/7/02, 7/8/02 and 24/8/02). Quantity (calculated as 4.73 ML/ha) and timing of irrigation (calculated when irrigation requirement was around 100 mm) was based on the up-dated FAO ‘CROPWAT’ computer program (FAO, 1988) using meteorological data for Anau and allowing for ground water contribution which varied between 0.4 and 2.3 mm/day. Rainfall from 2/4/02 until harvest was 129.8 mm. Irrigations wetted plots up to the plant line and applied 1 ML/ha per irrigation. Design was a randomized complete block with four replications. Plot size was 4 rows (90cm spacing) x 20 m. Spacing within the row for desired plant populations was calculated and 3 seeds planted at each position by hand using graduated markers to determine the position. Plantings were thinned to one plant per position on 6/5/02 to give a plant population of 88,000 plants/ha.

Hand weeding of all plots was conducted 30/4/02-3/5/02, 21-24/5/02 and 14-17/6/02. Shielded spraying with Gramoxone (350 mg/l a.i.) was carried out using a knapsack spray on 21/6/02, 25-28/6/02, 4/7/02 and 15-17/7/02.

Where phenological observations were made, 10 plants from the middle row of each plot were marked using cotton cloths at the first and last position on 14/6/02 and phenological progress of each plant was recorded using the COTMAN system from 20/6/02 to 7/8/02 for
all plots. Numbers of open bolls were counted 21/8/02, 30/8/02, 5/9/02 and 13/9/02 and mature plant heights on 14/8/02.

On 16/9/02 plant populations of the middle rows of each plot were determined. Open and green bolls from the 10 marked plants in each middle row were counted at the same time and a 50-boll sample taken at random (top, middle and bottom of canopy in sequence) from the 10 marked plants. Seed cotton yields from all plots were then calculated. All collected 50 boll samples were ginned on 2-3/10/02 using a laboratory saw gin manufactured in Tashkent located at ARPEC. Ginned seed was weighed 11/10/02 and fibre in each sample calculated. GOT and fibre yields per plot were then calculated. Fibre samples were analyzed for length, uniformity, strength and micronaire using equipment provided by the European Union’s ‘Support to the Cotton Sector Project’ at CRI Iolatan. Analyses were conducted by Professor U. Kechagia, Director of the Fibre Institute, Greece.

7.2.2 Row spacing x cultivar x plant population experiment at ARPEC

The factors investigated were row spacing (60 and 90 cm), cultivar (*Gossypium barbadense* L. cultivars Iolatan 5, long sympodia; Ashgabat 97, medium sympodia; and 9938E, short sympodia) and plant population (6, 9, 12, 15 and 18 plants/m²) on growth, quality and yield of cotton. The selection of higher plant populations compared with Chapter 5 was based on the higher optimum population required for long staple (*G. barbadense*) cottons (Kudratullaev, 1981). The experimental design was a split-split plot (row spacing = main plot, cultivar = sub-plot, plant population = sub-sub-plot) with 4 replications. Plot size was 3 rows x 6 m for 90 cm row spacing and 5 rows x 6 m for 60 cm row spacing. Spacing within the row for desired plant populations was calculated and 3 seeds planted at each position by hand using graduated markers to determine the position. Plants were thinned to one plant per
position on 6/5/02 to give desired plant populations. Plant populations were measured on 24/5/02 and a few plots adjusted to required populations by thinning 10/6/02. Details of land preparation and cultural practices are given in Chapter 3.

Ten plants from the middle row of each plot were marked using cotton cloths at the first and last position on 14/6/02 and phenological progress of each plant was recorded using the COTMAN system (for details see Chapter 8) from 17/6/02 to 12/8/02 for all plots. Numbers of open bolls were counted 30/8/02, 3-4/9/02 and 11-12/9/02 and mature plant heights on 29-30/8/02. Details of harvest techniques, yield and fibre quality estimations as in 7.2.1 above.

Harvest was on 20/9/02 (Rep 1) 23/9/02 (Rep 2) 24/9/02 (Rep 3) and 25/9/02 (Rep 4). Open and green bolls from the 10 marked plants in each middle row were counted at the same time and a 50-boll sample taken at random (top, middle and bottom of canopy in sequence) from the 10 marked plants for all experiments. Seed cotton yields from all plots were then calculated. All collected 50-boll samples were ginned on 2-3/10/02 at ARPEC, using a laboratory saw gin manufactured in Tashkent. Ginned seed was weighed on 11/10/02 and fibre in each sample calculated. GOT and fibre yields per plot were then calculated.

Inspection of the experimental area during the course of the experiment suggested that various plots may have been salt-affected. The effect on all 120 plots was evaluated on a 1-4 scale: none, noticeable, high or very high. After discussions with the Chief Biometrician at NIAB, Cambridge, it was decided that analysis using intensity of apparent salting as the covariate would be used in analysis of experimental results. Except for effect of plant population number of bolls/10 plants, this analysis did not change the significance of treatment effects from an analysis undertaken without using salt as a covariate, probably
because the major salting damage was confined to one block of replicates. Results without the covariate analysis are therefore presented.

7.3 Results and discussion

7.3.1 Number of irrigations experiment at ARPEC, 2002

In the ANOVA, number of irrigations had significant effects on the yield of seed cotton and cotton fibre (P<0.01) and on the yield components of bolls per plant, per row, and per hectare (P<0.01). There was no effect on ginning out-turn (GOT) (P>0.05). The effects of irrigation number on yield and yield components are summarized in Table 7.1.

Table 7.1. Effect of irrigation number on yield and yield components of the cultivar Turkmenbashi 1 at ARPEC, Turkmenistan in 2002.

<table>
<thead>
<tr>
<th>Number of irrigations</th>
<th>Yield seed cotton (kg/ha)</th>
<th>GOT (%)</th>
<th>Yield fibre (kg/ha)</th>
<th>Boll number per plant</th>
<th>Boll number per row</th>
<th>Boll number per ha (‘000)</th>
<th>Boll weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>749</td>
<td>0.39</td>
<td>291</td>
<td>2.9</td>
<td>433</td>
<td>241</td>
<td>3.10</td>
</tr>
<tr>
<td>2</td>
<td>1632</td>
<td>0.37</td>
<td>608</td>
<td>5.1</td>
<td>766</td>
<td>426</td>
<td>3.80</td>
</tr>
<tr>
<td>3</td>
<td>2352</td>
<td>0.38</td>
<td>898</td>
<td>6.4</td>
<td>964</td>
<td>536</td>
<td>4.32</td>
</tr>
<tr>
<td>5</td>
<td>2730</td>
<td>0.38</td>
<td>1036</td>
<td>7.7</td>
<td>1119</td>
<td>622</td>
<td>4.37</td>
</tr>
<tr>
<td>Mean</td>
<td>1866</td>
<td>0.38</td>
<td>708</td>
<td>5.5</td>
<td>821</td>
<td>456</td>
<td>3.90</td>
</tr>
</tbody>
</table>

l.s.d. (0.01) 891 NS

1 Treatment means not statistically significant (P≥0.05).

The highest yield, obtained with five irrigations, represented a 264% increase for seed cotton and 254% increase in fibre yield compared to a single irrigation. However, the increase in yield from three to five irrigations was not statistically significant (P≥0.05).

Increasing irrigation numbers to three significantly increased the number of bolls/plant and bolls/hectare, as well as increasing boll weight, but for none of these yield components was
the response to two further irrigations significant.

The absence of any significant advantage for five irrigations over three irrigations is similar to results reported by Palomo and Godoy (1998) and Vories and Glover (2000). It should also be noted that as around one ML/ha was added per irrigation, the total water added by three irrigations (4 ML/ha including the pre-irrigation) is lower than the optimum reported by Rejepov and Kudratullaev (1979) in earlier experiments conducted in Turkmenistan. The difference could well be due to build-up of ground water over the period of time which elapsed between the older research and that reported here. The contribution of groundwater to crop requirements is between 0.4-2.3 mm/day and must be factored into any irrigation prediction model (FAO, 1988; TACIS, 1999).

Decreasing rate of responses to successive irrigation treatments may be explained by the fact that older leaves, which develop under water stress, reach lower potential thresholds before a response in stomatal conductance is triggered (Krieg, 1986). Osmotic adjustment, a process whereby the plant allows water potential to decrease without accompanying decrease in turgor, has received attention as a probable component of resistance to drought in cotton leaves (Oosterhuis and Wullschleger, 1987). Boll growth is maintained during water stress longer than vegetative growth. Bolls have fewer stomata than leaves and therefore lose water less readily. Bolls maintain turgor more than vegetative tissue and have more potential for growth after stress as they are able to keep growing on the last 1/3 of available soil moisture (Hearn and Constable, 1984).

The effects of irrigation number on quality characteristics are summarized in Table 7.2. The ANOVA showed significant effects of increasing irrigation number on 100-seed weight
(P<0.01), micronaire (P<0.05), and UHML and ML (P<0.05), but there were no significant effects (P>0.05) on strength (Pressley Index), UI or SFI.

Table 7.2  Effect of irrigation number on quality characteristics of Turkmenbashi 1 at ARPEC, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Number of irrigations</th>
<th>100-seed weight (g)</th>
<th>Micronaire (microns)</th>
<th>Length – UHML (inches)</th>
<th>Length – ML (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.60</td>
<td>3.69</td>
<td>0.98</td>
<td>0.79</td>
</tr>
<tr>
<td>2</td>
<td>8.95</td>
<td>3.74</td>
<td>1.04</td>
<td>0.86</td>
</tr>
<tr>
<td>3</td>
<td>9.06</td>
<td>4.19</td>
<td>1.08</td>
<td>0.89</td>
</tr>
<tr>
<td>5</td>
<td>9.65</td>
<td>4.31</td>
<td>1.09</td>
<td>0.89</td>
</tr>
<tr>
<td>Mean</td>
<td>8.82</td>
<td>3.98</td>
<td>1.05</td>
<td>0.86</td>
</tr>
<tr>
<td>l.s.d (0.05)</td>
<td>0.43</td>
<td>0.41</td>
<td>0.07</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Increasing the number of irrigations to three significantly increased the mean value of all attributes above that for one or two irrigations, and the further increase to five irrigations was not significant except for 100-seed weight (Table 7.2). Irrigation had no significant effect on fibre strength (average 8.1 Pressley Units), short fibre index (SFI – average 17.6%) or uniformity index (UI – average 81.6%). The fact that cessation of irrigation had only a partial effect on fibre quality in this experiment supports the suggestion that fibre quality is more strongly influenced by events early in the flowering period (Jones and Wells, 1998). In this experiment this would have coincided in the initial treatments with a period when the effects of an early pre-irrigation and early irrigation were still affecting fibre quality.

The effects of number of irrigations on crop development are summarized in Table 7.3. Number of irrigations affected plant development early in the growing season in this experiment, but there was less effect as the season progressed. At maturity, the number of green bolls/10 plants and the percentage of green bolls increased (P<0.05) with greater numbers of irrigations, but the increases were small (Table 7.3). Similarly, the number of
open bolls per 10 plants increased with the number of irrigations, at least up to two
irrigations, at 119DAP, 135DAP, 140DAP and 148DAP. At 119DAP, after an increase at
two irrigations, the trend was for increased numbers of irrigations to decrease the number of
open bolls/10 plants.

Table 7.3 Effect of irrigation number on maturity characteristics of cultivar
Turkmenbashi 1 at ARPEC, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Number of irrigations</th>
<th>Green bolls at maturity /10 pl</th>
<th>Green bolls at maturity %</th>
<th>Open bolls 119 DAP /10 pl</th>
<th>Open bolls 119 DAP %</th>
<th>Open bolls 126 DAP /10 pl</th>
<th>Open bolls 126 DAP %</th>
<th>Open bolls 135 DAP /10 pl</th>
<th>Open bolls 135 DAP %</th>
<th>Open bolls 140 DAP /10 pl</th>
<th>Open bolls 140 DAP %</th>
<th>Open bolls 148 DAP /10 pl</th>
<th>Open bolls 148 DAP %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>14.0</td>
<td>48.7</td>
<td>75.7</td>
<td>97.3</td>
<td>29.3</td>
<td>97.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>23.0</td>
<td>47.6</td>
<td>66.6</td>
<td>94.9</td>
<td>50.5</td>
<td>94.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>10.3</td>
<td>18.1</td>
<td>46.9</td>
<td>81.3</td>
<td>60.0</td>
<td>81.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>1.3</td>
<td>6.8</td>
<td>9.0</td>
<td>23.7</td>
<td>69.7</td>
<td>67.5</td>
<td>69.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.25</td>
<td>0.33</td>
<td>13.5</td>
<td>30.9</td>
<td>53.2</td>
<td>85.8</td>
<td>51.8</td>
<td>85.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.s.d. (0.05)</td>
<td>0.7</td>
<td>0.8</td>
<td>9.5</td>
<td>16.6</td>
<td>22.8</td>
<td>16.9</td>
<td>11.8</td>
<td>16.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The percentage of open bolls is a better measure of crop development than the number of
green bolls per plant. This measure was affected by the number of irrigations at 119DAP,
126DAP (P<0.01) and 135DAP (P<0.05), although not later in the season at 140 (average
95.2%) and 148 DAP (average 100%). More irrigation applications led to a reduced
percentage of open bolls. These results are consistent with other reports that increasing
irrigation frequency delays crop maturity (Karche, 1984) or, conversely, that water stress hastens crop maturity.

Irrigation frequency affected crop phenological characteristics in this experiment at the point
of and after flowering, having significant effects on the numbers of sympodia with first
position flowering points (FP1) at 75DAP (but not earlier) and nodes above the white flower
(NAWF) on the main stem at 85DAP (P<0.05), 93DAP, 100DAP, 106DAP (P<0.01) and
112DAP (P<0.05). The data are given in Table 7.4. Only characteristics for which there was a significant treatment effect (P<0.05) are presented.

Table 7.4. Effect of number of irrigations on the phenological characteristics of the cultivar Turkmenbashi 1 at ARPEC, Turkmenistan in 2002

<table>
<thead>
<tr>
<th>Number of irrigations</th>
<th>Sympodia with FP1 175 DAP</th>
<th>NAWF (DAP)</th>
<th>Δ NAWF</th>
<th>85 DAP to NAWF=5</th>
<th>Plant height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>85</td>
<td>93</td>
<td>100</td>
<td>106</td>
<td>112</td>
</tr>
<tr>
<td>1</td>
<td>7.9</td>
<td>5.8</td>
<td>3.8</td>
<td>2.3</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>8.7</td>
<td>7.0</td>
<td>7.0</td>
<td>4.8</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>8.3</td>
<td>6.8</td>
<td>7.5</td>
<td>5.3</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>8.3</td>
<td>6.8</td>
<td>7.0</td>
<td>6.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Mean</td>
<td>8.3</td>
<td>6.6</td>
<td>6.3</td>
<td>4.6</td>
<td>3.3</td>
</tr>
<tr>
<td>l.s.d (0.05)</td>
<td>0.29</td>
<td>0.8</td>
<td>1.2</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

1 number of nodes with sympodial branches carrying first position squares at 75 days after planting
2 number of nodes above the first white flower 85 days after planting
3 change in nodes above the first white flower over a 21 day period
4 number of days until nodes above the white flower was 5 from 85 DAP
5 number of days after planting till there were 5 nodes above the first white flower, or ‘cutout’

Increasing number of irrigations increased the NAWF observed in each treatment at every observation made after flowering. Lower numbers of irrigations led to moisture stress in boll development and early physiological ‘cut-out’. As all treatments received a pre-planting irrigation (31/3/02) and another irrigation on 6/6/02, there was not enough time for moisture stress to affect development when measured during square development in June (average numbers of sympodia with FP1 squares in each treatment were 6.6, 7.7 and 8.3 squares per plant at 64DAP, 71DAP and 75DAP, respectively). After flowering, moisture stress affected development of bolls. This is reflected in the low numbers of bolls both per plant and per hectare at low irrigation frequencies (Table 7.1) and the significant effect of irrigation frequency on both these parameters. Boll filling was also affected and this was reflected in the lower boll weights at lower irrigation frequencies (Table 7.1).
Number of irrigations had no significant effect on the position of the first fruiting node (FFN) when measured 64DAP (average 6.2). This effect may be attributed to a pre-planting irrigation on 31/3/02 and another on 6/6/02, which did not allow enough time for moisture stress to affect development when measured during square development in June.

Maximum FP1 sympodia number (number of sympodia with FP1 squares) was 8.7 in this experiment for plants that had a white flower. This may be compared to 9.2 for the COTMAN ‘target development curve’ based on data from Arkansas, USA (Oosterhuis et al., 1996b). Rate of descent of the NAWF ‘curve’ was from 0.202 nodes per day for one irrigation to 0.107 for 5 irrigations (average 0.158) and was affected by number of irrigations (5% level of significance). This may be compared to 0.213 nodes per day in the COTMAN ‘target development curve’ and a rate of descent of the NAWF ‘curve’ in the population x gap experiment at Anau reported above of 0.168 – 0.186 nodes/day (average 0.173 nodes/day). Slower descent of five irrigations treatment is probably due to late 1st flower initiation.

Days to NAWF=5 from 85DAP (first ‘BOLLMAN’ observation) and total days from planting to NAWF=5 were significantly affected by number of irrigations (see Table 7.4).

The effects on crop phenology observed in this experiment indicate that low irrigation treatment regimes caused early cut-out and lower levels of NAWF at any given date. These findings accord well with those reported by Bourland et al. (1997b).

The considerable amount of information contained in Table 7.4 can be summarized as a series of COTMAN ‘curves’ for the four irrigation treatments. These appear in Chapter 8.
Number of irrigations significantly (P<0.05) affected plant height when measured on 14/8/02 in this experiment. Heights varied from 41.6 cm for the treatment with one irrigation, to 67.1 cm for the treatment with five irrigations (Table 7.4).

7.3.2 Row spacing x cultivar x plant population experiment at ARPEC

In the ANOVA for this experiment, the only significant effects were for the main effect of row spacing on yield (of seed cotton and fibre) and boll number per hectare (all P<0.05); for the effect of cultivar on yield (seed cotton and fibre), boll count (per plant, per row and per hectare) and ginning out turn (GOT) (all at P<0.01); and for plant population on bolls per plant (P<0.01). No interaction between any of these three variables was significant (P>0.05).

The narrow row spacing of 60 cm compared with the standard 90 cm gave a 25% increase in the yield of seed cotton (1,444 kg/ha to 1,806 kg/ha) and a 17% increase in fibre yield (474 kg/ha to 556 kg/ha, P<0.05) (Table 7.5).
**Table 7.5**  Effects of row spacing, plant population and cultivar on yield and yield components of three long staple cultivars at ARPEC, Turkmenistan 2002

<table>
<thead>
<tr>
<th></th>
<th>Yield seed cotton/ha</th>
<th>Yield fibre/ha</th>
<th>GOT</th>
<th>Bolls/10 plant</th>
<th>Bolls/row</th>
<th>Seed cotton/row (g)</th>
<th>Fibre/row (g)</th>
<th>Bolls/ha (‘000)</th>
<th>Boll weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Row spacing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 cm</td>
<td>1806</td>
<td>556</td>
<td>0.303</td>
<td>80.1</td>
<td>269.6</td>
<td>653</td>
<td>196</td>
<td>749</td>
<td>2.274</td>
</tr>
<tr>
<td>90 cm</td>
<td>1444</td>
<td>474</td>
<td>0.321</td>
<td>70.5</td>
<td>332.6</td>
<td>777</td>
<td>261</td>
<td>616</td>
<td>2.342</td>
</tr>
<tr>
<td>Mean</td>
<td>1625</td>
<td>515</td>
<td>0.312</td>
<td>75.3</td>
<td>301.1</td>
<td>715</td>
<td>229</td>
<td>683</td>
<td>2.308</td>
</tr>
<tr>
<td>l.s.d. (<em>P</em> 0.05)</td>
<td>99</td>
<td>19.5</td>
<td>NS¹</td>
<td>9.5</td>
<td>52.8</td>
<td>NS¹</td>
<td>13.6</td>
<td>36.3</td>
<td>NS¹</td>
</tr>
<tr>
<td><strong>Cultivar</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iolatan 5</td>
<td>1174</td>
<td>327</td>
<td>0.278</td>
<td>57.3</td>
<td>208.9</td>
<td>501</td>
<td>137</td>
<td>480</td>
<td>2.124</td>
</tr>
<tr>
<td>Ashgabat 97</td>
<td>1922</td>
<td>664</td>
<td>0.346</td>
<td>86.6</td>
<td>357.0</td>
<td>858</td>
<td>303</td>
<td>812</td>
<td>2.427</td>
</tr>
<tr>
<td>E9938</td>
<td>1779</td>
<td>555</td>
<td>0.312</td>
<td>82.1</td>
<td>337.6</td>
<td>785</td>
<td>244</td>
<td>756</td>
<td>2.373</td>
</tr>
<tr>
<td>Mean</td>
<td>1625</td>
<td>515</td>
<td>0.312</td>
<td>75.3</td>
<td>301.2</td>
<td>715</td>
<td>229</td>
<td>683</td>
<td>2.308</td>
</tr>
<tr>
<td>l.s.d. (<em>P</em> 0.05)</td>
<td>121</td>
<td>48.0</td>
<td>0.031</td>
<td>10.86</td>
<td>50.09</td>
<td>58.3</td>
<td>25.1</td>
<td>54.0</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Plant population, plants/ha</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60,000</td>
<td>1465</td>
<td>457</td>
<td>0.307</td>
<td>110.1</td>
<td>267.1</td>
<td>657</td>
<td>206</td>
<td>593</td>
<td>2.272</td>
</tr>
<tr>
<td>90,000</td>
<td>1696</td>
<td>520</td>
<td>0.303</td>
<td>88.7</td>
<td>313.3</td>
<td>746</td>
<td>229</td>
<td>709</td>
<td>2.330</td>
</tr>
<tr>
<td>120,000</td>
<td>1583</td>
<td>496</td>
<td>0.308</td>
<td>66.7</td>
<td>294.3</td>
<td>699</td>
<td>220</td>
<td>664</td>
<td>2.289</td>
</tr>
<tr>
<td>150,000</td>
<td>1681</td>
<td>521</td>
<td>0.306</td>
<td>59.0</td>
<td>314.3</td>
<td>733</td>
<td>227</td>
<td>717</td>
<td>2.322</td>
</tr>
<tr>
<td>180,000</td>
<td>1699</td>
<td>533</td>
<td>0.337</td>
<td>52.0</td>
<td>316.6</td>
<td>739</td>
<td>259</td>
<td>730</td>
<td>2.327</td>
</tr>
<tr>
<td>Mean</td>
<td>1625</td>
<td>515</td>
<td>0.312</td>
<td>75.3</td>
<td>301.2</td>
<td>715</td>
<td>229</td>
<td>683</td>
<td>2.308</td>
</tr>
<tr>
<td>l.s.d. (<em>P</em> 0.05)</td>
<td>NS¹</td>
<td>47.2</td>
<td>NS¹</td>
<td>11.6</td>
<td>NS¹</td>
<td>NS¹</td>
<td>NS¹</td>
<td>NS¹</td>
<td>NS¹</td>
</tr>
</tbody>
</table>

¹ NS – Differences in treatment means non-Significant (*P*=0.05)

The three cultivars were all significantly different from each other in yield. The highest yielding cultivar was Ashgabat 97, with 1,922kg/ha of seed cotton and 664kg/ha of fibre across all row spaces and plant populations. 9938E yielded 1,779 seed cotton and 555kg/ha fibre, whilst the lowest yields were from Iolatan 5 with 1,174kg/ha seed cotton and 327kg/ha fibre. For ginning out turn (GOT), Iolatan 5 averaged 28% across both row spaces and all populations. Ashgabat 97 35% and 9938E 31% (see Table 7.5). As one of the main
characteristics cotton cultivars are bred for in Turkmenistan is GOT, this result could be expected. Cultivar had a significant effect (P<0.01) on number of bolls/hectare, this being 481, 818 and 764 thousand bolls for the cultivars Iolatan 5, Ashgabat 97 and 9938E, respectively.

High GOT is positively correlated with the economic efficiency of the cotton crop (Galanopoulou-Sandouca, 2002). Improvement of GOT also provides stable yields because less weight and energy are required to produce lint than boll (Bourland and Oosterhuis, 2001). Recently, GOT has achieved importance for European Union cotton breeders in Spain and Greece, as subsidies are given on lint cotton yield and not on seed cotton yield (Galanopoulou–Sandouca, 2002). The same may soon happen in Turkmenistan (Dr. G. Muradov, Turkmen Agricultural University, pers. comm. 2002), although payments are currently made by the state to producers on a seed cotton basis.

These results indicate that the value of Iolatan 5 as a ‘self-defoliating’ cultivar must be balanced against its poor ginning out turn and low yield. On the other hand, Iolatan 5 possesses good fibre quality, particularly fibre strength (see Table 7.6). The newly developed cultivar, Iolatan 14, which possesses good GOT, yield and superior fibre qualities (TACIS, 2001), may provide a suitable substitute for Iolatan 5.

Johnson and Walhood (1970) found higher interception of light during boll filling explained yield differences in narrow row compared to conventional row planted cotton. Krieg (1992) also suggested a direct relationship between increased light interception and increased yields for narrow row spaces. Experimental work by Pettigrew et al. (1992) found that most of the
variation in the lint yields reported in their experiments on row spacings was related to light interception (measured as ‘PPFD’ or photosynthetic photon flux density). Peng and Kreig (1991) and Heitholt et al. (1992) have found increased yields in rows of less than 1 m are due to increased light interception in these rows during vegetative and early reproductive growth, when metabolites are being partitioned between vegetative and floral parts. Light interception may affect production of photosynthate directly (Cothren, 1999), but may also affect the microclimate of the canopy (Bakasov et al., 1976), particularly temperature (Reddy et al., 1991a,b). It may be inferred from these experiments that where the partitioning between reproductive and vegetative parts of the plant are the same, light (PPFD) interception will in many cases be the same.

In experiments with plants spaced equidistantly in the row and between rows, Mass (1997) found that inter-plant competition commenced shortly after adjacent plants made physical contact within and across the row. When plants are closer together in the row than between rows, it may be assumed that competition commences in the row before it does between rows for light as well as nutrients. In experiments conducted by Boquet and Coco (1993) two different row spaces had no effect on per unit area total vegetative growth or on the distribution of growth between vegetative and floral parts (main stems, sympodial and monopodial branches). It was hypothesized that solar interception was also the same at both row spacings, and differences in yield between row spacings in the experiment may be attributed to less competition within rows at the same plant population for the narrower row spacing, rather than for greater light interception at differing row spacings (rows at 102 cm spacing were planted at 16 seeds/m but at 75 cm spacing at 12 seeds/m so that plant population would be the same for each row spacing).
In the row spacing x cultivar x population experiment conducted at ARPEC there was an
effect of row spacing on seed cotton and fibre yield, but no plant population effect. There
was no effect of row spacing on flowering pattern or phenology in this experiment (see
Tables 7.12 and 7.13) but a pronounced plant population effect. This suggests that light
interception in both row spacings was the same, but light interception (as well as perhaps
soil nutrients and water) between plants with different inter-plant spaces in the rows was not
the same. It is therefore suggested that the effect of row spacing in this experiment is due to
variation in plant spacing per row (plant populations per row) rather than to factors such as
solar interception and canopy structure at differing row spaces. Hoskinson et al. (1972) and
Maas (1997) have reached similar conclusions from their experiments, in which interplant
competition, rather than solar interception, determined yield levels at different row spaces.
‘Skip-row’ planting system experiments may also support this hypothesis. Skip-rows have
larger row spaces as alternate rows are ‘skipped’. King et al. (1986) conducted a three-year
experiment comparing skip-row planting patterns in Alabama, USA. On a per row basis,
yields increased 29-62% using skip-row planting patterns, but when yields were calculated
on the basis of area, yields were 12-46% less on skip-row patterns. These results are similar
to those in the experiment at ARPEC in which yield per row was 777g for the 90 cm row
spacing compared to 653g for the 60 cm row spacing (although these differences were not
significant, P>0.05). However, on a per hectare basis, the corresponding yields were 1,444
kg/ha for the 90 cm rows and 1,806 for the 60 cm rows (these differences were significant
P<0.05).

This experiment was designed to have the same plant populations in each row spacing
arrangement, so that at the same plant populations, plants in the 60 cm row spacing had
fewer plants per row than those in the 90 cm treatments, and therefore potentially less intra-
row competition. The relationship between row spacing, plant spacings in the rows and
inter-plant competition may be seen in the effect of row spacing on the parameters bolls/10 plants and bolls/row. Increasing row spacing from 60 to 90 cm decreased bolls/10 plants from 80.1 to 70.5 (Table 7.5, non-covariate analysis). This indicates increased stress on individual plants at the greater row spacing, where inter-plant spacing was reduced. Higher average plant populations in the rows at the 90 cm spacing (53 plants/10 m row), compared with rows at 60 cm spacing (36 plants/10 m) led to an opposite trend in the number of bolls/row (333 vs. 270) at 90 cm. That is, bolls/row increased for the 90 cm spacing. However, as the 90 cm plots had 3 rows compared to five for the 60 cm rows, the 90 cm row plots had less bolls per plot and therefore less yield per area than the 60 cm row plots.

Number of bolls per hectare was affected by row spacing (P<0.05). Thousands of bolls per hectare were 621 for 90 cm and 754 for 60 cm spacing. Row spacing had no effect on GOT (mean 0.312 for all plots) and boll weights (mean 2.385 g for all plots). These results are similar to those reported by Hoskinson et al. (1972) in which the effect of doubling plant populations (from 100-200,000) on bolls per plant when row width was constant was almost the same as doubling row width. Doubling row width in one of these experiments halved plant population in the row but increased the number of bolls/plant from 1.8-3.0. In another experiment reported by the same authors, doubling row width halved plant population per row but increased bolls/plant from 1.8-3.6.

The higher minimum plant populations used in this experiment compared to those reported in Chapter 5 (6 plants/m² c.f. 3 plants/m² at ARPEC and 2 plants/m² at CRI) may also explain the lack of a plant population response in this experiment. The main contributor to the significant effect of plant population on yield in Chapter 5 were the very low ‘starting’ plant populations (3 and 2 plants/m²).
There was no cultivar x plant population interaction on yield in this experiment. Kerby et al. (1990a) have reported similar results. However, other experiments report an interaction between genotype and plant population. In a number of these, ‘okra-leaf’ cultivars or ‘okra-leaf’ isolines of normal leafed cultivars, respond differently to increased plant populations, due to the lower LAI and PPFD interception of the okra leaf shape (Heitholt, 1994). In others experiments that report cultivar x plant population interaction on yield, cultivars with very different maturities have been used (Gannaway et al., 1995).

The number of bolls/10 plants declined significantly as plant populations increased (see Table 7.5, non-covariate analysis), just as it did in the plant population x gap experiments at both Anau and Iolatan and the plant population x irrigation experiment at Iolatan in Chapter 5 and in many experiments previously reported (Anastassiou-Lefkopoulou and Sotiriadis, 1984; Jones and Wells, 1997; Hoskinson et al., 1972; Mass, 1997; Wanjura and Bilbro, 1977).

Turning to effects on fibre quality, greater row spacing reduced fibre strength (P<0.05) in the experiment, but no other quality characteristics were affected by either row spacing or plant population. This is in contrast to other experiments in which fibre length and strength were not influenced by row spacing or plant population (Briggs and Patterson, 1970; Hawkins and Peacock, 1973). Differences in experimental results may be explained by the differing species used in the experiments; G. hirsutum in the experiments of Briggs and Patterson (1970) and Hawkins and Peacock (1973), compared to G. barbadense in the experiment reported here. Jones and Wells (1997, 1998) in more recent studies demonstrated greater fiber length, strength, micronaire, fiber percentage and boll mass from bolls produced in the first six weeks compared to the last two weeks of flowering. Low plant populations had more bolls maturing later than higher plant populations. Accumulated heat
units at the two times explained the fiber differences in these experiments and this conclusion is also noted by a number of researchers (Quisenberry and Kohel, 1975; Meredith and Bridge, 1973; Verhalen et al., 1975). The variability of weather conditions across a number of experiments at various stages of flowering may therefore explain the inconsistent effects of plant population and row spacing on fiber properties (Koli and Morrill, 1976).

Cultivar predictably affected all fibre quality (micronaire, short fibre index, strength, ML and UHML) in the experiment (P<0.01), as the cultivars used had been specifically bred at the CRI, Iolatan for different fibre qualities. Varying plant population had no significant effects on any attribute of quality. The data are summarized in Table 7.6.

**TABLE 7.6** Effect of row spacing, cultivar and plant population on fibre quality of three long staple cultivars at ARPEC, Turkmenistan 2002

<table>
<thead>
<tr>
<th></th>
<th>Micronaire</th>
<th>Short Fibre Index</th>
<th>Strength (PI)</th>
<th>ML</th>
<th>UHML</th>
<th>100 Seed weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Row spacing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 cm</td>
<td>3.7</td>
<td>13.4</td>
<td>9.62</td>
<td>1.08</td>
<td>1.29</td>
<td>8.40</td>
</tr>
<tr>
<td>90 cm</td>
<td>3.6</td>
<td>13.6</td>
<td>9.43</td>
<td>1.07</td>
<td>1.28</td>
<td>8.14</td>
</tr>
<tr>
<td>Mean</td>
<td>3.7</td>
<td>13.5</td>
<td>9.52</td>
<td>1.08</td>
<td>1.29</td>
<td>8.27</td>
</tr>
<tr>
<td>l.s.d (P&lt;0.05)</td>
<td>NS</td>
<td>NS</td>
<td>0.20</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Cultivar</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iolatan 5</td>
<td>3.2</td>
<td>12.9</td>
<td>9.96</td>
<td>1.16</td>
<td>1.37</td>
<td>8.81</td>
</tr>
<tr>
<td>Ashgabat 97</td>
<td>3.7</td>
<td>15.0</td>
<td>9.18</td>
<td>1.00</td>
<td>1.21</td>
<td>7.90</td>
</tr>
<tr>
<td>E9938</td>
<td>4.0</td>
<td>12.7</td>
<td>9.43</td>
<td>1.07</td>
<td>1.27</td>
<td>8.10</td>
</tr>
<tr>
<td>Mean</td>
<td>3.7</td>
<td>13.5</td>
<td>9.52</td>
<td>1.08</td>
<td>1.29</td>
<td>8.27</td>
</tr>
<tr>
<td>l.s.d (P&lt;0.05)</td>
<td>0.06</td>
<td>0.25</td>
<td>0.17</td>
<td>0.01</td>
<td>0.01</td>
<td>0.19</td>
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<td><strong>Plant population, plants/ha</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60,000</td>
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<td>13.50</td>
<td>9.61</td>
<td>1.08</td>
<td>1.28</td>
<td>8.56</td>
</tr>
<tr>
<td>90,000</td>
<td>3.6</td>
<td>13.69</td>
<td>9.64</td>
<td>1.08</td>
<td>1.29</td>
<td>8.29</td>
</tr>
<tr>
<td>120,000</td>
<td>3.7</td>
<td>13.15</td>
<td>9.39</td>
<td>1.08</td>
<td>1.28</td>
<td>8.27</td>
</tr>
<tr>
<td>150,000</td>
<td>3.6</td>
<td>13.50</td>
<td>9.52</td>
<td>1.09</td>
<td>1.30</td>
<td>8.10</td>
</tr>
<tr>
<td>180,000</td>
<td>3.6</td>
<td>13.74</td>
<td>9.47</td>
<td>1.07</td>
<td>1.27</td>
<td>8.13</td>
</tr>
<tr>
<td>Mean</td>
<td>3.7</td>
<td>13.5</td>
<td>9.52</td>
<td>1.08</td>
<td>1.29</td>
<td>8.27</td>
</tr>
<tr>
<td>l.s.d (P&lt;0.05)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

1 NS – Differences in means non-Significant (P=0.05)
The only significant ($P<0.05$) interaction affecting fibre quality in this experiment was that between row spacing and cultivar on short fibre (Table 7.7).

**TABLE 7.7** Row spacing x cultivar interaction on short fibre index (SFI) of three long staple cultivars at ARPEC, Turkmenistan on 30th August 2002

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Iolatan 5</th>
<th>Ashgabat 97</th>
<th>E9938</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row 60 cm</td>
<td>13.0</td>
<td>15.1</td>
<td>12.1</td>
</tr>
<tr>
<td>Row 90 cm</td>
<td>12.7</td>
<td>14.9</td>
<td>13.3</td>
</tr>
</tbody>
</table>

L.s.d ($P_{0.05}$) = 0.34.

Increased populations ($P<0.01$) reduced the number of green bolls/10 plants at harvest, but did not affect the percentage of green bolls at this stage (Table 7.8). Row spacing ($P<0.01$) affected the percentage of green bolls at harvest (Table 7.8).

Increased populations reduced the number of open bolls/10 plants on 30/8/2002, 4/9/2002 and 12/9/2002, but did not affect the percentage of open bolls at any date. The effects of row spacing, cultivar and plant population on maturity characteristics is given in Tables 7.8.
Table 7.8  Effect of row spacing, cultivar and plant population on maturity of three long staple cultivars at ARPEC, Turkmenistan 2002

<table>
<thead>
<tr>
<th></th>
<th>Open bolls/10 plants</th>
<th>% open bolls 137 DAP</th>
<th>Open bolls/10 plants</th>
<th>% open bolls 142 DAP</th>
<th>Open bolls/10 plants</th>
<th>% open bolls 150 DAP</th>
<th>Green bolls/10 plants</th>
<th>% Green bolls</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Row spacing</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>60 cm</td>
<td>18.57 22.1 28.9 49.2</td>
<td>58.0 12.55 14.1</td>
<td>22.18 30.8 33.6 49.7</td>
<td>54.2 79.9 8.35 11.9</td>
<td>20.38 26.5 31.3 42.1</td>
<td>51.7 69.0 10.45 13.0</td>
<td>1.11</td>
<td></td>
</tr>
<tr>
<td>90 cm</td>
<td>22.18 30.8 33.6 49.7</td>
<td>54.2 79.9 8.35 11.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>20.38 26.5 31.3 42.1</td>
<td>51.7 69.0 10.45 13.0</td>
<td>1.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.s.d (P 0.05)</td>
<td>NS¹ NS¹ NS¹ NS¹</td>
<td>NS¹ NS¹ NS¹ NS¹</td>
<td>NS¹ NS¹ NS¹ NS¹</td>
<td>NS¹ NS¹ NS¹ NS¹</td>
<td>NS¹ NS¹ NS¹ NS¹</td>
<td>NS¹ NS¹ NS¹ NS¹</td>
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<tr>
<td><strong>Cultivar</strong></td>
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<td></td>
</tr>
<tr>
<td>Iolatan 5</td>
<td>16.20 29.3 26.3 51.6</td>
<td>42.9 84.2 2.22 4.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ashgabat 97</td>
<td>21.90 23.7 33.0 35.1</td>
<td>53.9 56.3 15.95 17.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E9938</td>
<td>23.03 26.3 34.5 39.4</td>
<td>58.4 66.4 13.17 16.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>20.38 26.5 31.3 42.1</td>
<td>51.7 69.0 10.45 13.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.s.d (P 0.05)</td>
<td>NS¹ NS¹ NS¹ 5.7</td>
<td>7.43 9.128 NS¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Plant population, plants/ha</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60,000</td>
<td>25.75 20.7 40.6 33.0</td>
<td>69.6 56.9 19.58 17.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90,000</td>
<td>23.29 24.6 35.6 38.5</td>
<td>58.0 62.4 12.33 13.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120,000</td>
<td>18.79 27.6 29.6 44.5</td>
<td>48.6 72.0 10.13 16.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150,000</td>
<td>19.25 31.6 28.0 46.8</td>
<td>44.7 74.0 5.12 8.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180,000</td>
<td>14.79 27.9 22.5 47.4</td>
<td>37.6 79.6 5.08 10.0</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>20.38 26.5 31.3 42.1</td>
<td>51.7 69.0 10.45 13.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.s.d (P 0.05)</td>
<td>NS¹ NS¹ 3.22</td>
<td>3.90 NS¹ 4.59 NS¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ NS – Differences in treatment means non-Significant

There was a row spacing x cultivar interaction on number of open bolls / 10 plants when measured on 30th August 2002 (Table 7.7) and a plant population and cultivar interaction on number of green bolls at harvest (Table 7.9). Gannaway et al. (1995) noted a plant population x cultivar interaction on maturity in their experiments in which cultivars were selected on the basis of their maturity. The cultivars in this experiment were not chosen on the basis of maturity, but differences in maturity between the cultivars used were demonstrated (Table 7.8).
Table 7.9  Row spacing x cultivar interaction on number of open bolls / 10 plants of three long staple cultivars at ARPEC, Turkmenistan on 30th August 2002

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Iolatan 5</th>
<th>Ashgabat 97</th>
<th>E9938</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row spacing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 cm</td>
<td>18.5</td>
<td>20.7</td>
<td>16.6</td>
</tr>
<tr>
<td>90 cm</td>
<td>14.0</td>
<td>23.1</td>
<td>29.5</td>
</tr>
</tbody>
</table>

L.s.d (P 0.05) = 7.0.

Table 7.10  Plant population x cultivar interaction on number of green bolls at harvest of three long staple cultivars at ARPEC, Turkmenistan on 30th August 2002

<table>
<thead>
<tr>
<th>Cultivar/PP</th>
<th>60,000 p/ha</th>
<th>90,000 p/ha</th>
<th>120,000 p/ha</th>
<th>150,000 p/ha</th>
<th>180,000 p/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iolatan 5</td>
<td>2.37</td>
<td>2.75</td>
<td>2.50</td>
<td>1.00</td>
<td>2.50</td>
</tr>
<tr>
<td>Ashgabat 97</td>
<td>25.75</td>
<td>21.75</td>
<td>19.87</td>
<td>6.00</td>
<td>6.37</td>
</tr>
<tr>
<td>9938E</td>
<td>30.62</td>
<td>12.50</td>
<td>8.00</td>
<td>8.38</td>
<td>6.37</td>
</tr>
</tbody>
</table>

L.s.d (P 0.05) = 3.891

Cultivar affected the percentage of open bolls on 4/9/2002 (P<0.05) and 12/9/2002 (P<0.01) with the cultivar Iolatan 5 having 86.6% of it’s total bolls open compared to 57.0% for Ashgabat 97 and 66.8% for 9938E on 12/9/2002. Five days earlier, the comparable percentages were 53.8, 35.9 and 39.8 for the three cultivars. As Iolatan 5 has been developed for early ‘self-defoliation’ this result was wholly expected. The problem in breeding superior early maturing cultivars, when there is a negative linkage between earliness and other important agronomic characters, such as yield and fiber quality (Chlichlias and Galanopoulou, 1976), is evident in cultivars such as Iolatan 5.

Plant population, although having no statistically significant effect on yield across the three cultivars and two row spacing in the experiment, had a considerable effect on the phenological characteristics of the three long staple cultivars as expressed as NAWF. These effects are summarized in Table 7.12. The only significant effects on phenological characteristics before boll development stage were those of cultivar on square retention on
17/6/2002 and 24/6/2002 (P<0.05) and first flowering node (FFN) (P<0.01); and of plant population on FP1 positions per plant 17/6/2002 and 24/6/2002 (P<0.01). There was a plant population x cultivar interaction at 112 DAP (see Table 7.11). A similar interaction has been noted above in the experiments of Gannaway et al. (1995) in which cultivars were selected on the basis of their maturity.

**TABLE 7.11** Cultivar x plant population (plants/ha) interaction on NAWF of three long staple cultivars at 112 DAP at ARPEC, Turkmenistan, 2002

<table>
<thead>
<tr>
<th>Cultivar/Population</th>
<th>60,000</th>
<th>90,000</th>
<th>120,000</th>
<th>150,000</th>
<th>180,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iolatan 5</td>
<td>5.816</td>
<td>4.650</td>
<td>5.354</td>
<td>4.800</td>
<td>5.038</td>
</tr>
<tr>
<td>Ashgabat 97</td>
<td>4.588</td>
<td>4.650</td>
<td>4.125</td>
<td>3.575</td>
<td>4.388</td>
</tr>
<tr>
<td>9938E</td>
<td>5.259</td>
<td>4.275</td>
<td>4.013</td>
<td>4.371</td>
<td>4.013</td>
</tr>
</tbody>
</table>

L.s.d \(_{P 0.05}\) = 0.484

As the rate of change of NAWF was not significantly affected by population, differences in the number of days to NAWF=3.5 (cut out for long staple cultivars, Kerby and Hake, 1996) can be accounted for by differences in number of sympodia with FP1 fruiting bodies at around 70 DAP, a result similar to that of the plant population x gap experiment at ARPEC reported in Chapter 5.

Ashgabat 97 had higher retention (75.70%, 78.18%) than E9938 (69.97%, 75.55%) and Iolatan 5 (65.84%, 70.48%) on both dates. This parameter was reflected in greater numbers of bolls/ha for this cultivar at harvest (818, 764 and 481 thousand bolls/ha for the cultivars Ashgabat 97, 9938E and Iolatan 5, respectively). First fruiting node would be expected to vary between cultivars, particularly for this characteristic since the cultivars used in the experiment were selected on the basis of growth habit (open and tall, intermediate and medium and compact and low).
Plant population did not affect square retention in this experiment, but cultivar did (Table 7.12). This result conflicts with that of Bednarz et al. (2000) who found that lower plant densities led to plants with increased fruit retention. It did, however, agree with Bednarz et al. (2000) in that lower plant populations resulted in greater fruit production per plant. This indicates that in this experiment plant population affected total numbers of fruiting bodies produced rather than their retention. Hearn and Constable (1984) found that shading can instigate loss of squares, whereas shedding of small bolls at the top of the plant late in the season is a result of competition for assimilates. This is an indication that light interception may not have been important early in the floral development of plants at varying row spacings and populations in this experiment.

As there was no significant effect of row spacing on the phenology of plants in this experiment, it is suggested that solar interception was the same at both row spaces, as it has been shown that light interception affects phenological development; and that when light interception as measured by photosynthetic photon flux density is equal in canopies at two row spaces; their phenological development is not significantly different (Boquet and Coco, 1993). This supports the hypothesis already advanced that differences in yield in the experiment at different row spacings may be simply attributed to less competition within rows at the same plant population for the narrower row spacing, rather than for greater light interception (photosynthetic photon flux density) at differing row spaces. The findings of this experiment reported are similar to those of Boquet and Coco (1993) who found that row spacing had no effect on distribution of growth of main stems, sympodial and monopodial branches, but significantly affected cotton yield.
### TABLE 7.12 Summary of analysis of variance of phenology, row spacing x cultivar x plant population experiment at ARPEC, T’menistan 2002

|                     | FP1 63 DAP<sup>2</sup> | Square retention 63 DAP | FP1 70 DAP<sup>2</sup> | Square retention 70 DAP | First fruiting node 70 DAP<sup>3</sup> | NAWF 81 DAP<sup>3</sup> | NAWF 84 DAP | NAWF 91 DAP | NAWF 100 DAP | NAWF 105 DAP | NAWF 112 DAP | NAWF 119 DAP | ΔN AWF<sup>4</sup> (38 d) | DAP to NAWF=3.5<sup>5</sup> |
|---------------------|------------------------|-------------------------|------------------------|-------------------------|---------------------------------------|-------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|----------------------------|-----------------------------|
| (RS) Row Space      | NS                     | NS                      | NS                     | NS                      | NS                                    | NS                      | NS          | NS          | NS          | NS          | NS          | NS          | NS          | NS                             | NS                           |
| (V) Cultivar        | NS                     | **                      | NS                     | *                       | **                                    | NS                      | **          | *           | NS          | NS          | NS          | NS          | NS          | NS                             | NS                           |
| (PP) Plant Pop.     | **                     | NS                      | **                     | NS                      | NS                                    | *                       | **          | **          | **          | **          | NS          | NS          | NS          | NS                             | NS                           |
| RS x V I-A<sup>1</sup> | NS                    | NS                      | NS                     | NS                      | NS                                    | NS                      | NS          | NS          | NS          | NS          | NS          | NS          | NS          | NS                             | NS                           |
| RS x PP I-A<sup>1</sup> | NS                    | NS                      | NS                     | NS                      | NS                                    | NS                      | NS          | NS          | NS          | NS          | *           | NS          | NS          | NS                             | NS                           |
| PP x V I-A<sup>1</sup> | NS                    | NS                      | NS                     | NS                      | NS                                    | NS                      | NS          | NS          | NS          | NS          | NS          | NS          | NS          | NS                             | NS                           |
| RSxVxPP I-A<sup>1</sup> | NS                    | NS                      | NS                     | NS                      | NS                                    | NS                      | NS          | NS          | NS          | NS          | NS          | NS          | NS          | NS                             | NS                           |

1 IA = interaction between named treatments  
2 number of nodes with sympodial branches carrying first position squares at 63, 70 days after planting  
3 number of nodes above the first white flower 81 days after planting  
4 change in nodes above the first white flower over a 38 day period  
5 number of days after planting till there were 3.5 nodes above the first yellow flower, or ‘cutout’. Significances **, * for p < 0.01; 0.01 < p < 0.05. NS = Non-Significant (P=0.05)
TABLE 7.13  Effect of row spacing, cultivar and plant population on phenology of three long staple cultivars at ARPEC, Turkmenistan 2002

<table>
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<tr>
<th></th>
<th>FP1 63 DAP</th>
<th>Square retention 63 DAP</th>
<th>FP1 70 DAP</th>
<th>Square retention 70 DAP</th>
<th>First fruiting node 70 DAP</th>
<th>NAWF 81 DAP</th>
<th>NAWF 84 DAP</th>
<th>NAWF 91 DAP</th>
<th>NAWF 100 DAP</th>
<th>NAWF 105 DAP</th>
<th>NAWF 112DA P</th>
<th>NAWF 119DA P</th>
<th>81DAP to NAWF =3.5</th>
<th>Δ NAWF (38 d)</th>
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<td><strong>Mean</strong></td>
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<td>70.2</td>
<td>6.53</td>
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<td>NS¹</td>
<td>NS¹</td>
<td>NS¹</td>
<td>NS¹</td>
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</tbody>
</table>

¹ NS – Differences in means non-Significant (P=0.05)
Increasing plant population from 6 to 18 plants/m² decreased FP1 sympodia from 5.5 to 5.0 when measured on 17/6/2002 and from 6.9 to 6.0 when measured on 24/6/2002 (Table 7.13). The effects of the same increase in plant population on crop NAWF were to decrease NAWF from 8.1 to 7.2 when measured 81 DAP; from 7.5 to 6.3 84 DAP; from 6.2 to 4.7 at 100 DAP and from 5.2 to 4.3 112 DAP. These results reflect larger plastochrons at high populations (Munro, 1971; Munro and Farbrother, 1969) that may result from lower total available carbohydrate levels in leaves at high plant populations (Saleem and Buxton, 1976). The effects of increasing plant populations on plant phenology were the same in this experiment as those reported in the plant population x gap trial at ARPEC (Chapter 5).

The considerable amount of information on the influence of plant populations on changes to NAWF can be conveniently summarized as a series of COTMAN ‘curves’ for the five plant population treatments. These curves are presented in Chapter 8.

### 7.4 Further discussion

The number of irrigations had a significant effect on the yield of seed cotton and fibre and on the yield components of bolls per plant, per row, and per hectare in the experiment conducted at ARPEC. The highest yield, obtained with five irrigations, represented a 264% increase for seed cotton and 254% increase in fibre yield compared to a single irrigation. However, the increase in yield from three to five irrigations was not statistically significant. Increasing irrigation numbers to three significantly increased the number of bolls/plant and bolls/hectare, as well as increasing boll weight, but for none of these yield components was the response to two further irrigations significant. These results indicate that the 5-5.5 ML recommended by Rejepov and Kudratullaev (1979) may now be in excess of current requirements. The difference may be due to the increasing contribution of ground water due
to many years of irrigation in the area studied (TACIS, 1999). Reduction of number of recommended irrigations of 1 ML/ha from five to three in cotton growing areas may have considerable environmental as well as economic benefits to Turkmenistan.

The fact that cessation of irrigation had only an effect on only some fibre characteristics in this experiment supports the suggestion that fibre quality is more strongly influenced by events early in the flowering period (Jones and Wells, 1998). In this experiment this would have coincided in the initial treatments with a period when the effects of an pre-irrigation earlier in the season and early irrigation were still affecting the results.

The percentage of open bolls in the irrigation experiment at ARPEC was affected by the number of irrigations at 119DAP, 126DAP (P<0.01) and 135DAP, although not later in the season at 140DAP and 148DAP. Crop phenology was significantly affected by irrigation in this experiment, both in terms of NAWF during the duration of the experiment and also in the number of days after planting to cutout. The target development curves generated by the COTMAN crop monitoring system are particularly responsive to drought (Bourland et al., 1997b). The COTMAN curves developed from the irrigation experiment were also responsive to water stress. This result establishes the utility of the COTMAN system under Turkmen conditions.

In the row spacing x cultivar x population experiment, row spacing affected yield of seed cotton and fibre and boll number per hectare. Cultivar affected yield of seed cotton and fibre, boll count (per plant, per row and per hectare) and ginning out turn (GOT). Population affected numbers of bolls per plant but not yield. Row spacing and population had little effect on fibre quality in this experiment, but cultivar had a predictably strong effect on fibre quality.
The effect of plant population on crop phenology in the row spacing x cultivar x population experiment was not matched by a corresponding effect on crop yield, as it was in the experiment on irrigation. In the experiment on number of irrigations reported above there was a corresponding effect of the treatments on both crop phenology and yield.

As plant densities may affect plant phenology without bringing about an increase in yield in some experiments (Bednarz et al., 2000; Buehring and Dobbs, 2000; Buxton et al., 1977), while in others plant density affects yield as well as phenological characteristics of the cotton plant (Kerby et al., 1990a), it may be expected that COTMAN graphs will in some cases relate to treatment differences in yield in cotton (for example in the number of irrigations experiment) but in others be un-related to any differences in yield (the row spacing x cultivar x plant population experiment). These differences are discussed more fully in Chapter 8.

The row spacing x cultivar x plant population experiment had a significant response in crop phenology to plant population, well described by a series of COTMAN curves, unrelated to treatment differences in either yield or maturity. However, there was no response to row spacing of any phenological character measured in this experiment (Table 7.12). The COTMAN curves for the row space treatments in this experiment, shown in Figure 7.1 below, reflect this lack of differences in phenology of plants at the two row spaces.
This leads to the important conclusion that light interception in both canopies was the same, leading to the same phenological development being observed at the two row spaces. Therefore yield differences can be attributed to different inter-plant spaces in different rows rather than a row effect *per se*. The fact that increasing row spacing from 60 to 90 cm decreased number of bolls per plant from 8 to 7 indicates increased stress on the individual plant at the greater row spacing where intra-plant spacing was reduced. Higher plant populations in the row in the 90cm row spacing (average of 53 vs. 36 plants/row over all treatment plots) increased bolls/row for the 90 cm spacing (333 vs. 270).

This is an example of how the COTMAN curve may have utility in certain instances (for example when phenology of two canopies is the same) in advancing hypotheses to explain treatment differences in experiments, rather than simply characterizing them. It also illustrates how using a system like COTMAN to describe treatment differences in crop phenology may in particular cases substitute detailed observations of the developing crop for the sometimes expensive and complicated equipment needed to measure light interception.
interception in the crop canopy. This makes it a valuable research tool in Turkmenistan and other Central Asian states with limited finances for research and restrictions on the import of certain equipment. This point is enlarged upon in Chapter 8.

Long staple cultivars may have their phenology characterized by COTMAN curves that relate days after planting to development of floral parts (NAWF). COTMAN curves for the cultivars Iolatan 5, Ashgabat 97 and 9938E were developed for the first time in Turkmenistan from the data recorded in the row spacing x cultivar x population experiment reported in this Chapter and are presented in Chapter 8.

Early maturity, which is closely related to parameters such as NAWF, is negatively correlated to yield and fibre quality characteristics in cotton breeding (Chlichlias and Galanopoulou, 1976). As the optimum development pattern of a new cultivar should exploit the whole growing season as defined by the prevailing conditions of temperature, water availability and solar radiation (Galanopoulou – Sendouca and Oosterhuis, 2003); premature cutout may be assessed in relation to the a cultivar’s phenology. COTMAN curves can be used for long staple cultivars to determine if they develop and cutout too early in the season, just as they can be used to characterize maturity in medium staple cultivars (see Chapter 5). This technique has recently been introduced and studied under Greek conditions. For the first time in 2001, an experiment with 9 cotton cultivars was carried out in Greece (Thessaly) to characterize their maturity using COTMAN curves (Kalfountzos et al., 2002). COTMAN curves may also be of considerable assistance to cotton breeders in Turkmenistan.
7.5 Conclusions

Reduction of number of recommended irrigations of 1 ML/ha from five to three in cotton growing areas may afford considerable environmental as well as economic benefits to Turkmenistan.

That COTMAN curves, developed from the irrigation experiment and summarized in Figure 8.7 of this thesis, were responsive to water stress, establishes the utility of the COTMAN system under Turkmen conditions.

Yield differences in the row spacing x cultivar x population experiment were attributed to different inter-plant spaces in different rows rather than a row effect *per se*.

In the row spacing x cultivar x population experiment, where phenology of 60 cm and 90 cm canopies was the same, COTMAN curves were used in advancing hypotheses to explain treatment differences, rather than simply characterizing them. Using a system like COTMAN to describe treatment differences in crop phenology may in particular cases substitute detailed observations of the developing crop for expensive and often unavailable equipment needed to measure light interception in the crop canopy.
CHAPTER 8 USE OF THE COTMAN SYSTEM IN TURKMENISTAN AND
OTHER SHORT-SEASON COTTON GROWING COUNTRIES IN CENTRAL
ASIA.

8.1 Using plant monitoring in management decisions – the COTMAN system

‘COTMAN’ is a system of crop monitoring and management that is based on a detailed body of knowledge of the development of the cotton plant built up over ten years. It integrates development in any one year with patterns of expected plant development and responses to weather built up over several years (Zhang et al., 1994a). The ‘COTMAN’ system, and the assumptions about crop growth therein, particularly the use of ‘NAWF’ and ‘NAWF=5’ to describe the physiological state of the crop and crop maturity, have recently been experimentally verified (Bondada, 1994; Bondada et al., 1996a; Brown et al., 2001; Kharboutli, 2001) and are described in Chapter 2.

Once bolls begin to compete with vegetative growth the rate of node development slows (Kerby et al., 1987a). This decline is shown in Figure 8.1. Main-stem nodal development relative to reproductive development, shown in Figure 8.1 is based on long-accepted plant development sequence for upland cotton (Tharp, 1960). The curve assumes that first square appears at 35 days after planting (DAP), first flower at 60 DAP with NAWF = 9.25 and physiological cutout (defined as NAWF=5) at 80 DAP (Bourland et al., 1997a).
The importance of the first fruiting position ‘FP1’ is recognized in monitoring systems like ‘COTMAN’ that only use this fruiting position when counting square and boll retention (Oosterhuis, 1996b). The presence or absence of FP1 on the various fruiting branches in the COTMAN system is denoted by ‘1’ or ‘0’ as in Figure 8.2 below. A COTMAN ‘squaremap’ of Figure 8.2 would be expressed 1,1,0,1,0,1.

Figure 8.1  Pace of cotton crop development in Arkansas, USA measured in days after planting (after Oosterhuis, 1998)

Figure 8.2  First position squares on the cotton plant as recorded by the COTMAN crop monitoring system (after Oosterhuis, 1998)
Fruit growth has a higher priority for carbohydrates than does vegetative growth. ‘Nodes above the white flower’ (NAWF) measures the difference between rate of new node formation and rate at which FP1 flowers move up the plant (Oosterhuis, 1996b).

Both the initial value of NAWF and the rate at which it declines provide good estimates of the balance between vegetative and reproductive sinks (Kerby et al., 1987). By plotting squaring nodes and boll development the rate of flowering in the cotton crop can be measured (Figure 8.3). The slower nodal development after the first white flower has developed is due to the stress imposed by developing bolls on the plant, the ‘boll load’ (Oosterhuis et al. 1996a).

![Figure 8.3](image)

**Figure 8.3** Plotting cotton squaring nodes to show pace of flowering change in days after planting of the cotton crop in Arkansas, USA (after Oosterhuis, 1998)

The COTMAN system utilizes a target development curve or TDC (shown in Figure 8.4) by charting the appearance of firstly squaring nodes and subsequent to the appearance of the first fertilized flower (after around 9.25 squaring nodes have been developed) by counting
the nodes above the first fertilized or white flower (Bourland et al., 1997b; Oosterhuis et al. 1996b).

Figure 8.4  The COTMAN crop monitoring ‘Target Development Curve’ for Arkansas, USA (after Oosterhuis, 1998)

Cutout earlier than the target (80 days after planting) leads to earliness and reduced productivity, while cutout later than the target results in exposure of the crop to risky late season events such as thunderstorms and insect attack (Bourland et al., 1997b; Zhang et al., 1994a; Zhang et al., 1994b).

Just how well COTMAN can be applied in short season areas outside the USA remains to be seen. Recent research undertaken in Greece by Kalfountzos et al. (2002) confirms that COTMAN may be used by farmers in short season cotton areas outside the USA.
8.2 Use of the COTMAN system to describe differences in yield and maturity in experiments in Turkmenistan

The COTMAN system is primarily a tool for improving crop management on farms. The limited use of insecticides in Turkmenistan means that the COTMAN system will have little utility in timing termination of insecticide application, as it does in Arkansas. However, the system may have utility in Turkmenistan as a crop monitoring tool to predict defoliation.

As the COTMAN system has only recently been refined to the extent that it can be used as a crop monitoring system by farmers, the use of COTMAN to describe or explain treatment differences in experimental work has only recently commenced (Prof. D.M. Oosterhuis, pers. comm. 2003).

The experimental work reported in Chapters 5 and 7 is examined in this Chapter to see if the treatment differences in yield, maturity and phenology reported can be either summarized, described, or be explained, by hypotheses involving the COTMAN system.

The advantage of using crop monitoring measures like NAWF, that indicate the balance between vegetative and reproductive growth, to characterize or explain treatment differences in experiments; is that they may in certain situations substitute detailed observations of the growing plant for the equipment needed to measure such variables as net carbon assimilation rates and partitioning (Baker et al., 1983; Brown et al., 1985; Stapleton et al., 1973).

Crop phenology, specifically the partitioning of growth into vegetative and floral parts, may also be used to draw conclusions on light interception (Boquet and Coco, 1993). Light
interception may be assumed equal in two crop canopies or treatments that show the same phenological development (Boquet and Coco, 1993; Heitholt et al., 1993; Krieg, 1992). Therefore monitoring systems that involve descriptions of crop phenology, may have use in describing or explaining treatment differences which result in equal light interception in treatment canopies. As the equipment needed to measure light interception is currently not available in Turkmenistan, the use of a crop monitoring system like COTMAN may have utility in replacing this equipment under certain conditions in experimental work.

8.3 Explanation of experimental results in terms of COTMAN

8.3.1 Plant density x gap experiment at ARPEC

Plant population had an effect on plant maturity in this experiment. Increased plant population significantly decreased both numbers of green bolls per plant and the percentage of green bolls at harvest. Population also significantly affected numbers of open bolls per plant at three dates - 127DAP, 138DAP and 145DAP; however, percentages of open bolls at these dates were not affected by plant population.

As crop phenological characteristics in this experiment were recorded as nodes above the white flower (NAWF), and as NAWF=5 is an accepted measure of crop maturity or physiological 'cut-out' (see Chapter 2), there is a strong agreement between treatment differences reported in plant maturity in this experiment and those based on phenology. Plant population had a significant affect on crop phenological characteristics in this experiment, effecting maximum number of fruiting nodes at 77DAP; nodes above the white flower on the main stem at 86, 91, and 105 (but not 112) days after planting and days to NAWF=5. As the rate of change of NAWF was not significantly affected by plant
population, differences in days to NAWF=5 can be accounted for by differences in maximum numbers of squaring nodes at 77DAP. Experimental plots took 103 days to ‘cut-out’ at 30,000 plants/ha compared to 100 days at 120,000 plants/ha. These results agree with those reported by Andries et al. (1971); Buxton et al. (1977); Ehlig et al. (1971); Hefner (1971); and Smith et al. (1979); and more recent research by Bednarz et al. (2000). They reflect larger plastochrons at high populations than those at low (Munro, 1971; Munro and Farbrother, 1969), resulting in a lower number of fruiting nodes at first flower at high plant populations. These may result from lower total available carbohydrate levels in leaves at high plant populations than in leaves of cotton grown at lower densities (Saleem and Buxton, 1976).

The results of the row spacing x cultivar x plant population experiment (Chapter 7), summarized in Table 7.8, also show that increasing population either hastens maturity (measured by number of green bolls/10 plant) or has no effect (as measured by % open bolls) on the long staple cultivars Iolatan 5, Ashgabat 97 and E9938. Differences between earlier work conducted in Turkmenistan ((Bakasov and Yagmurov, 1974; Kurbangeldiev, 1985) and that reported in this thesis may be attributable to the different patterns of maturity of new cultivars as reported in Gannaway et al. (1995).
The five COTMAN (technically speaking ‘BOLLMAN’) ‘curves’, drawn from phenological recordings for the five populations of Turkmenbashi 1, intersect the NAWF=5 line at different days after planting (Figure 8.5). This gives ‘cutout’ for each treatment and demonstrates earlier maturity at higher plant populations. The ‘curve’ for ARKANSAS, (using broken lines as it has not been constructed from data from this thesis) where the system was developed and has been most widely applied, is given for comparison.

The experimental evidence for relating population effects to phenology and yield is inconsistent. In some cases, plant density has affected phenology without affecting yield (Bednarz et al., 2000; Buehring and Dobbs, 2000; Buxton et al., 1977); whilst in others, plant density has affected both phenological characteristics and yield (Kerby et al., 1990a). There is no convincing causal connection between slightly earlier maturity in the plant density x gap experiment at ARPEC, and the yield differences reported to different plant population densities. Therefore, the treatment differences observed in maturity in the plant population x gap experiment at ARPEC can be explained and characterized in terms of the COTMAN system, but yield differences cannot.
8.3.2 Plant population x irrigation frequency experiment at CRI

Although there were considerable numerical differences between plant population treatments for DAP to NAWF=5 (140, 123, 117, 111 and 114 DAP for 20, 50, 80, 110 and 150,000 p/ha) there was no significance statistical differences between plant population treatments in DAP to NAWF=5 or ‘cut-out’. Nor was there a statistical difference between irrigation frequency treatments for DAP to NAWF=5. Therefore no significant effect of either factor on NAWF could be proven from this experiment. COTMAN curves that have substantially different shapes may be used to characterize differences in growth patterns in such experiments. As the slope of the NAWF curves was not significantly different in this experiment, growth patterns can be assumed to be the same for all treatments.

Therefore, unlike the plant population x gap experiment at ARPEC, the treatment differences observed in maturity in the plant population x irrigation frequency experiment at CRI cannot be explained in terms of the COTMAN system. Like the plant population x gap experiment at ARPEC, nor can yield differences.

8.3.3 Row spacing x cultivar x plant population experiment at ARPEC, Anau.

In this experiment plant population had an effect on crop phenology, significantly influencing NAWF when measured at 81, 84, 91, 100, 105 and 112 DAP. The considerable amount of information contained in Tables 7.12 and 7.13 can conveniently be represented by the COTMAN ‘curves’ in Figure 8.6.
Figure 8.6 COTMAN ‘curves’ for five plant population treatments of three long staple cotton cultivars at ARPEC, Turkmenistan in 2002

However, the phenological differences in treatment effects represented in the respective COTMAN curves is not reflected in treatment differences in yield or in maturity (other than % open bolls 137 DAP) measured by open bolls or % green bolls (measured at 142 or 150 DAP and harvest). There was no significant difference in DAP to NAWF=3.5 (cutout for long staple cultivars, Kerby and Hake, 1996) between plant population treatments. Thus the COTMAN curves developed for this experiment have utility in summarizing phenological measurements but not in characterizing / explaining treatment differences in yield or maturity observed.
8.3.4 Irrigation trial at ARPEC, Anau and Plant Population x Irrigation Experiment at CRI, Iolatan

In the irrigation trial at ARPEC, there were significant yield differences attributed to early cut-out of the low irrigation treatments. Thus maturity and yield in this experiment were closely related (Chapter 7). In this experiment, increasing irrigations led to a smaller percentage of open bolls. That is, irrigation delayed maturity and also significantly increased yield up to three irrigations. Increasing number of irrigations increased the NAWF observed in each treatment at every observation made after flowering, lower numbers of irrigations leading to moisture stress in boll development and early physiological ‘cut-out’. As all treatments received a pre-planting irrigation (31/3/02) and another irrigation on 6/6/02, there was not enough time for moisture stress to affect development when measured during square development in June (average numbers of sympodia with FP1 squares in each treatment were 6.6, 7.7 and 8.3 squares per plant at 64DAP, 71DAP and 75DAP respectively). After flowering, moisture stress affected the development of bolls, which is reflected in the low numbers of bolls both per plant and per hectare at low irrigation frequencies (see Table 7.1) and the significant effect of irrigation frequency on both these parameters. Boll filling was also affected. This is reflected in the lower boll weights at lower irrigation frequencies (see Table 7.1).

Treatment differences both in maturity and yield can be conveniently represented with COTMAN curves for each of the irrigation treatments in Figure 8.7. All curves indicate all treatments developed late relative to the TDC. The slope of the treatments three and four (3 and 5 irrigations) was very close to the TDC, showing boll development with few constraints after an early slow growth start.
Figure 8.7  COTMAN ‘curves’ for four irrigation treatments (T1=one, T2=two, T3=three and T4=five) of Turkmenbashi 1 at ARPEC, Turkmenistan in 2002

In the plant population x irrigation experiment conducted at CRI, Iolatan increasing irrigation number to the cultivar Iolatan 7 increased yield of seed cotton, but did not effect maturity in terms of percentage green bolls at maturity or as DAP to NAWF=5. The COTMAN curves for the irrigation treatments are given in Fig. 8.8. It should be noted that only the first irrigation treatment has a ‘curve’ that crosses the NAWF=5 line and can be said to have reached physiological ‘cut-out’. All other treatments do not cross this line or reach cut-out. This is in keeping with the comments made in Chapter 5 that difficulties preventing movement of water between irrigation treatments may have meant that some treatments received more water than they should have. This observation may also be related to the later maturity of Iolatan 7, as discussed in Chapter 5. There was no significant response to irrigation treatments in DAP to NAWF=5 in this experiment. Thus, as in the
case of the row spacing x cultivar x population experiment conducted with long staple cultivars at ARPEC, the COTMAN curves developed for this experiment have utility in summarizing phenological measurements but not in characterizing / explaining treatment differences in yield or maturity observed.

![Graph showing COTMAN curves for four irrigation treatments (0, 1, 2, and 5) of Iolatan 7 in the population x irrigation experiment at CRI, Turkmenistan in 2002.]

**Figure 8.8** COTMAN ‘curves’ for four irrigation treatments (0, 1, 2 and 5) of Iolatan 7 in the population x irrigation experiment at CRI, Turkmenistan in 2002

### 8.4 Limitations of COTMAN in describing treatment differences in experimental work in Turkmenistan

COTMAN is a crop-monitoring program designed for cotton farmers to continuously follow plant development during the season. It provides timely feedback on plant development and early detection of plant stress. It is also an aid to timely management decisions, particularly end-of-season decisions like defoliation and insect termination, by defining the last effective boll population at NAWF=5 (Oosterhuis 1998). However, COTMAN does not predict yield, and nor does it provide a ‘recipe’ for production (Oosterhuis 2001).
Recent research undertaken in Greece by Kalfountzos et al. (2002) confirms that COTMAN may be used by farmers in short season cotton areas outside the USA, once target development curves (TDCs) have been established for those areas by experimental observations. The COTMAN system is used in Arkansas in timing termination of insecticide application (Cochran et al., 1998; Oosterhuis et al., 1996). The limited use of insecticides in Turkmenistan means that the COTMAN system will have little utility for this, but may have utility in predicting defoliation.

It may be seen from the experimental results discussed above that COTMAN curves, used to describe phenological events in various experimental plantings of both medium and long staple cotton cultivars in Turkmenistan, can at times be used to describe / characterize treatment differences observed in maturity and yield and in some cases it cannot. This accords with prior experimental work (Bednarz et al., 2000; Buehring and Dobbs, 2000; Buxton et al., 1977; Kerby et al., 1990a) in which cotton crop phenology is at times related to yield and at times not.

A plant population x gap experiment at Anau had plant population treatment differences in maturity described by COTMAN curves. Irrigation experiments, in which some treatments may correspond to conditions described by Bourland et al. (1997b) of extreme drought stress, can have treatment differences in both maturity and yield characterized by COTMAN curves, as demonstrated in a frequency of irrigation experiment at Anau. However, in a plant density x irrigation experiment at Iolatan, COTMAN had utility in summarizing phenological measurements taken but not in characterizing / explaining treatment differences in yield or maturity observed.
On the other hand, a row spacing x cultivar x plant population experiment conducted using long staple cultivars at ARPEC, Anau had significant differences in phenological development of population treatments that were described well by a series of COTMAN curves (Figure 8.6), unrelated to treatment differences in either yield or maturity.

8.5 Utility of COTMAN in describing Target Development Curves for cotton cultivars in Turkmenistan and other Central Asian nations

Recent research undertaken in Greece by Kalfountzos et al. (2002) confirms that COTMAN may be used by farmers in short season cotton areas outside the USA, once target development curves (TDCs) have been established for those areas by experimental observations. It may also be necessary for cultivars newly developed in Arkansas to have TDCs determined for them if they differ appreciably from the standard ones (Bourland and Oosterhuis, 2001). As a corollary to this, TDCs developed for differing locations should allow wise selection of new cultivars developed outside those locations; for example, which Greek or U.S. cultivars may be of use in Turkmenistan and Central Asia and vice versa.

COTMAN ‘curves’ were developed for the first time in Turkmenistan in the field experiments reported in Chapters 5 and 7 at the Ahal Research and Production Experimental Center (ARPEC) at Anau and the Cotton Research Institute (CRI), Iolatan, in 2002.

The greatest utility to be had from the use of COTMAN curves in Turkmenistan is in the comparison of cultivars for maturity characteristics using their representative COTMAN curves.
The centralized nature of Central Asian cotton breeding, which reflected the centralized political system up to 1991, has meant that many cultivars are still used that do not respond well to local conditions. For example, in an attempt to breed early maturity into Turkmen cultivars, local breeders have produced cultivars like Turkmenbashi 1, that cut-out 2-3 weeks earlier than the season allows, resulting in substantial yield losses (Professor S. Gallanopolou-Seneca, Thessaly University, Greece, pers. comm. 2002). COTMAN has great utility in assessing such cultivars.

For example, the average rate of descent of the NAWF ‘curve’ for Iolatan 7 recorded in the plant population x irrigation experiment at CRI described in Chapter 5 was 0.076 nodes per day compared to 0.173 nodes per day for the cultivar Turkmenbashi 1 recorded in the plant population x gap trial reported in Chapter 5 at ARPEC, Anau. These varietal differences are plotted in Figure 8.9.

![Figure 8.9 COTMAN ‘curves’ for the development of Turkmenbashi 1 at ARPEC and of Iolatan 7 at CRI, Turkmenistan in 2002](image)

Although no direct comparison could be made, as sites were different in amounts of nitrogen fertilizer applied, soil type and accumulated heat units, these data indicate that the cultivar Iolatan 7 is later maturing than Turkmenbashi 1. This may account for the considerable differences in the yields of the two cultivars in these experiments (Iolatan 7 3,372 kg/ha
seed cotton vs. Turkmenbashi 1, 2661 kg/ha) and may also explain the observations of foreign cotton breeders that Turkmenbashi 1 is ‘cutting out’ too early in the season and may have taken the trend of Turkmen breeders to introduce early maturity into their cultivars too far.

This early maturity of Turkmenbashi 1 may also account for the reports by its breeder, Dr. A. Babaev, that this cultivar can be planted up to three weeks late in early May without any ‘yield penalty’ (Dr. A. Babaev, Senior Plant Breeder, ARPEC, pers. comm., 2002).

COTMAN also allows assessment of plant introductions from other countries to be made. This is very important in Central Asian states like Kyrgyzstan that have opened relationships with international plant breeding and certification agencies (IBPGR, UPOV and ISTA) and are currently building up a considerable genetic collection for trial plantings throughout the country. It will become important in Turkmenistan once this country also joins these international bodies and begins to explore plant genetic resource of other nations in a systematic way.

The yield and maturity of three long staple cultivars of cotton grown under the same conditions at ARPEC, reported in Chapter 7, gives an example of how different cultivars can be characterized in terms of COTMAN diagrams. The differences in maturity of the cultivars (i.e. days after planting when the curves cross the NAWF=3.5 line) are directly related to differences in phenology and are summarized in Figure 8.10.
Fig. 8.10 COTMAN ‘curves’ for the long staple cultivars Iolatan 5 (Var 1), Ashgabat 97 (Var 2) and 9938E (Var 3) at ARPEC, Turkmenistan in 2002

The COTMAN curves developed in the USA (change of 0.213 nodes per day in the ‘target development curve’ based on data in Oosterhuis et al., 1996b) can also be compared to the COTMAN curves developed in Greece by Kalfountzos et al. (2002). This procedure may be of considerable assistance in allowing Turkmen and other Central Asian cotton breeders to request appropriate cultivars developed in other short season areas like Arkansas, USA and Thessaly, Greece. The three sets of COTMAN representative curves can be characterized in Figure 8.11 (after Dr D. Bartziolis, Thessaly University, Greece, unpublished data 2002).
8.6 Utility of COTMAN in describing Target Development Curves for breeding drought tolerant cultivars in Turkmenistan and other Central Asian nations

The cotton plant originated from arid areas and exhibits some drought resistance. However, this characteristic is limited in most current commercial cultivars of cotton (Galanopoulou-Sendouca and Oosterhuis, 2003). The importance of water in all aspects of cotton development and the effects of water stress on cotton yield are documented in Chapters 2 and 7.

The relationship between COTMAN ‘curves’ for treatments 1 and 4 in Figure 8.7 above follows that of the relationship between ‘target development’ and ‘actual’ curves for a crop sufficiently watered and one affected by severe drought reported in the literature (Bourland et al. 1997b).
COTMAN curves of new introductions or crosses from drought tolerance breeding programs in Turkmenistan could be compared with the curves for standard cultivars grown under drought conditions. The information gained from this procedure could then be used in introduction and breeding programs aimed at producing drought tolerance of cotton cultivars in Turkmenistan and also in other Central Asian states.
CHAPTER 9 GENERAL DISCUSSION

9.1 Plant population

The objective of the work reported in this thesis, as stated in Chapter 1, was to improve cotton production in Turkmenistan. The methodology of the TACIS program was to concentrate on factors under the immediate control of farmers in a privatizing, but still heavily state-controlled, agriculture sector. These factors are most likely to result in immediate benefits, both to farmers and to the cotton sector. The aim of this thesis, in the light of this objective, was determined in a review of the main factors determining seed cotton yields in that country. These are quantity of irrigation water applied; nitrogen fertilization; sub-soiling or deep ploughing and plant population (Professor O. Regipov, Land and Water Institute, Ashgabat, pers. comm. 2002). Of these, the first two depend on state inputs and are closely controlled by local authorities. Thus there is no immediate scope for improvement here. The third requires cultivation equipment held collectively rather than individually. Hence of the four important factors, plant population is the only one that individual farmers can control.

The specific aim of the research was therefore to improve cotton production in Turkmenistan through optimizing plant population. The research was set within the phenological framework of the ‘COTMAN’ crop monitoring system (Oosterhuis et al., 1996a,b,c) which allowed the relationship between treatment effects (population, irrigation, row spacing) and crop maturity/yield to be examined in terms of crop phenology.

The first step towards achieving this aim was to determine if the low plant populations at two government farms, measured in June, 2001 were representative of populations in cotton
fields throughout the main cotton growing areas of Turkmenistan. The 2001 field survey (Chapter 4) confirmed this was the case, with plant populations being in the range 20-60,000 plants/ha (mean 45,000 plants/ha). Even in fields with the highest populations and yields, the populations were far below the optima reported in the world literature of around 100,000 plants/ha (Kerby et al., 1987a; Baker, 1976; Bilbro, 1972; Ehlig et al., 1971; Fowler and Ray, 1977; Galanopoulou-Sendouca et al., 1980 and Verhalen and Williams, 1992), including that from earlier work in Turkmenistan (Kudratullaev, 1981; Kudratullaev et al., 1981; Kurbangeldiev, 1985).

Although populations in the surveyed fields were low by these standards, this did not necessarily mean their yields could be significantly increased with higher populations. This is because genotype (Bourland and Oosterhuis, 2001; Heitholt, 1994; Heitholt et al., 1992), cultural conditions (Kerby et al., 1987a; Segarra et al., 1991; Smart and Bradford, 2000) and the long or short season environment in which cotton is grown (Verhalen and Williams, 1992) will all influence optimum populations. These have changed over time in Turkmenistan as they have elsewhere (Chapau et al., 1990). However, it did mean that optimum populations needed to be assessed for modern Turkmen cultivars under Turkmen environmental conditions (Babaev, 2001). This information would provide the benchmark by which to judge the populations reported in Chapter 4.

The field survey data also suggested that plant populations in lower-yielding fields might actually be near to the optimum for these fields. This suggestion was based on the trend for higher populations in these fields to result in reduced boll weight and number per plant, responses that are normally associated with inter-plant competition at high plant densities (Jones and Wells, 1997; Hoskinson et al., 1972; Mass, 1997; Wanjura and Bilbro, 1977). These responses may be due to high nitrogen requirements of developing seeds (Pettigrew
and Meredith, 1997) in the case of boll weight; and reduced over-all levels of assimilates, in the case of bolls/plant (Kerby et al., 1990a). Thus some constraint other than population was apparently reducing yield in these poor crops. In Central Asia, these factors may include compaction and poor root penetration (Avtonomov and Blijina, 1968; Batekaev et al., 1984; Sergaziev, 1977), salting (Rejepov et al., 1991), and limited water and soil nutrients (Rejepov et al., 1985; TACIS, 1999). There may be little value in increasing plant populations in these fields, without first addressing other constraints to yield.

Although irrigation water is a state controlled input in Turkmenistan, and in theory should not be limiting, in practice it may often be so (TACIS 2001). Although a study of field irrigation practice was beyond the scope of this thesis, it was considered important that any interaction between irrigation amount and population be evaluated.

Optimum population depends on both the cultivar (Heitholt, 1994; Heitholt et al., 1992; Pettigrew, and Meredith, 1994; Pettigrew et al., 1993; Sassenrath-Cole, 1995) and the environment in which it is grown (Brown, 1971; Lee, 1968; Bilbro, 1972). Therefore, field experiments reported in this thesis aimed first to determine the optimum plant populations for the newer medium staple G. hirsutum cultivars Turkmenbashi 1 and Iolatan 7 (Chapter 5), and the new long staple G. barbadense cultivars Iolatan 5, 9938E and Ashgabat 97 (Chapter 7). Other experiments explored the interaction between the environment (irrigation) and population. The results of the experiments at two locations, ARPEC and CRI, agreed with earlier findings in Turkmenistan (Kudratullaev et al., 1981). Optimum populations of G. hirsutum were 100,000 plants/ha in three experiments, across two locations. It would seem that the response to plant population of the new generation of Turkmen medium staple G. hirsutum cultivars is similar to that of the old.
A population of around 100,000 plants/ha is therefore the benchmark by which medium
staple populations in the field survey may be judged. Across the experiments in Chapter 5,
the yield increase from a population of 50-55,000 plants/ha to the optimum of 100,000
plants/ha was around 25\% (calculated by the average of percentage treatment differences x
regression coefficients in the respective experiments). Bearing in mind that the highest
population measured in the surveyed fields was under 60,000 plants/ha, it may be concluded
that substantial yield increases could be achieved readily in Turkmenistan by attention to
plant population. This assumes that inputs of water and nutrients would not be limiting. In
the group of highest yielding fields (Chapter 4), there was only a weak negative trend in boll
weight and boll number per plant with increasing population, suggesting there was little
inter-plant competition for resources such as water and nitrogen in these fields (Bondada,
1994; Bondada et al., 1997; Mass, 1997; Pettigrew and Meredith, 1997; Johnson et al.,
1974). In such fields there is a good chance that increased plant populations will increase
yields.

The conclusion that the optimum population for cotton in Turkmenistan is of the order of
100,000 plants/ha was based on experiments with \textit{G. hirsutum}. There was no response to
plant population in the range 60-180,000 plants/ha in the long staple \textit{G. barbadense}
cultivars Iolatan 5, Ashgabat 97 and E9938 in an experiment at ARPEC (Chapter 7).
Sassenrath-Cole (1995) found that \textit{G. hirsutum} had regular leaf shape during the season and
was diaheliotropic. \textit{G. barbadense} leaves were large and fairly flat early in the season but
progressively became more cupped at increasing main stem node positions and showed no
heliotropic response. As a result of the solar tracking response and leaf shape of the canopy,
light environment differed for the two species. Due to the light interception qualities of the
\textit{G. barbadense} canopy and a leaf type that allows more light penetration into the canopy,
Kittock et al. (1986) suggested that in the San Joaquin Valley, California \textit{G. barbadense} has
optimum plant populations greater than *G. hirsutum*. This is supported by experiments conducted with *G. barbadense* cotton cultivars by Kudratullaev *et al.* (1981) in Turkmenistan which show optimum plant populations for this species of up to 180,000 plants/ha. Californian data show no difference between *G. barbadense* and *G. hirsutum* cultivars in development of fruiting branch number with first position or ‘FP1’ flowers (Kerby and Hake, 1996). Nor was the general response of *G. barbadense* and *G. hirsutum* to plant population different in experiments conducted by Samra *et al.* (1985); seed cotton yields increased with increasing plant density but boll weight and lint percentage were unaffected. The lack of a plant population response in the row space x cultivar x population experiment may therefore not be representative of the field response of this species in Turkmenistan.

The lowest plant population treatment in the row space x cultivar x population experiment reported in Chapter 7 was twice that of the lowest in the experiments reported in Chapter 5. Also, a significant difference in yield attributable to row spacing in the row space x cultivar x population experiment may have been a *de facto* response to plant population through differences in interplant spaces within the rows. The stature of the long staple cultivars should also be taken into account. For example Tyaminov (1983) found that increasing plant populations of *G. barbadense* long staple cultivars 5904-I, Ashgabat 25 and Karchinski 2 from 100,000 to 300,000 p/ha decreased yield from 40.8 to 15.5 g/plant but increased yield/ha by 20.4% (average of three cultivars). However, all three of these are regarded as ‘dwarf’ types, whereas Iolatan 5 used in the row space x cultivar x population experiment was a tall, open (‘old style’) cultivar, 9938E a ‘dwarf’ and Ashgabat 97 intermediate between these two types. Similarly, Bakasov and Yagmurov (1974) used the relatively ‘dwarf’ 9647E in their experiments. Kerby *et al.* (1990a) has reported genotype x population
interactions in cottons exhibiting varying growth habits. Given the importance of the plant population x genotype interaction (Gannaway et al., 1995; Heitholt, 1994; Wells and Meredith 1986b) the experimental design may not have allowed for plant population effects to be adequately expressed. The effect of plant population on crop phenology in the row spacing x cultivar x population experiment was not matched by a corresponding effect on crop yield, as it was in the experiments reported in Chapter 5. This indicates that there may have been a de facto expression of plant population effect in this experiment through the effect of row spacing. This contention is based on work reported on light interception in the canopy reported by Krieg (1992), Pettigrew et al. (1992), Peng and Kreig (1991) and Heitholt et al. (1992) and is supported by the work of Boquet and Coco (1993). Similar conclusions have been reported by Hoskinson et al. (1972) and Maas (1997). An experiment using one long staple cotton cultivar at one row spacing at seven populations from 30,000 to 210,000 plants/ha could well be conducted in the future to re-test the response of long staple cultivars to plant population.

Increasing plant population had little effect on fiber properties at ARPEC, other than small effects on micronaire and upper half mean length. Brashears et al. (1968) and Briggs and Patterson (1970) found that high plant densities increased micronaire, rather than decreased it, like the experiment at ARPEC. However, Gannaway et al. (1995) and Johnson and Walhood (1972) found micronaire decreased with increasing plant population, in agreement with the experiment at ARPEC. Despite differences in upper half mean length and micronaire being significant in this experiment, they were quite small and would not have resulted in a lowering of grade or economic penalty to the cotton in the higher treatment levels. Grade would have been Soviet Grade IV (low middling – strict good ordinary or 35, 36 USDA grade) at all populations on the basis of UHML. Fineness would have improved from ‘coarse’ at lowest population to ‘average’ at all others. All samples would have been
classed ‘1 YAKSHI’ in the Turkmen classification (TACIS 2002a). Plant population increases had no effect on any fibre quality parameter in the other experiment in which it was possible to measure the affect of population on fibre quality, the row space x cultivar x population experiment on long staple cultivars at ARPEC.

Studies in which the effect of plant population on fibre length and strength was determined have generally found these to be unaffected by plant density; (Baker, 1976; Bridge et al., 1973; Briggs and Patterson, 1970; Hawkins and Peacock, 1973; Gannaway et al., 1995; Johnson and Walhood, 1972) or have found the effects of plant population to inconsistently affect fiber properties of length and strength (Koli and Morrill, 1976). Jones and Wells (1997, 1998) in more recent studies demonstrated greater fiber length, strength, micronaire, fiber percentage and boll mass from bolls produced in the first six weeks compared to the last two weeks of flowering. Low plant populations had more bolls maturing later than higher plant populations. Accumulated heat units at the two times explained the fiber differences in these experiments and this conclusion is also noted by a number of researchers (Quisenberry and Kohel, 1975; Meredith and Bridge, 1973; Verhalen et al., 1975). The variability of weather conditions across a number of experiments at various stages of flowering may therefore explain the inconsistent effects of plant population and row spacing on fiber properties (Koli and Morrill, 1976). Experiments by Elms et al. (2001) on a 5.3 ha irrigated field located in Lubbock, Texas, found that highest variability was observed for lint yield and production of fruiting sites, and lowest variability was observed for lint quality parameters. These results reflect the formation of fibre quality relatively late in the cropping cycle, at the time of maximum fibre elongation, 10-15 days after anthesis (Schubert, 1975; Benedict et al., 1999). The extent of the elongation period determines the fibre length (Benedict et al., 1999) and this may vary considerably depending on seasonal factors (Quisenberry and Kohel, 1975). Values for boll and fiber properties reported in Jones
and Wells (1998) were all positively correlated with ‘HUBP’ (‘HUBP’ = HU accumulated during boll development of each week of flowers) and micronaire and fibre percentage declined as ‘HUBP’ decreased below 400 heat units per week.

Increasing plant population advanced crop maturity, both in measures like green bolls at maturity and open bolls in the experiments conducted at ARPEC and CRI. It also reduced days after planting to ‘cut-out’ as characterized by NAWF=5 (measured at ARPEC). Eaton (1955) and Ray (1971) recognized two opposing effects of crowding on the cotton plant. The mainstem node of peak boll set is higher (this view being corroborated by more recent work by Bednarz et al., 2000) and hence crop maturity is delayed; whereas there are more early fruiting points, which will contribute to earliness. Either effect can be dominant depending on conditions and probably accounts for inconsistencies in reported effects of plant population on earliness. For example, Mohamad et al. (1982) found that increased populations delayed maturity while Smith et al. (1979) reported the opposite. Earliness is important, as it results in a higher yield through picking efficiency. Less deterioration of product quality occurs in the case of unfavourable conditions during harvest period, and late season pests may be avoided, Helicoverpa armigera in many instances, but more importantly in Turkmenistan, Bemisia tabaci (white-fly). Early harvest also permits the field to be prepared in time for the next crop in the rotation (Galanopoulou- Sendouca, 2002).

Optimum populations of G. hirsutum were found to be 100,000 plants/ha in the three experiments conducted in Turkmenistan in 2002. It would seem that the response to plant population of the new generation of Turkmen medium staple G. hirsutum cultivars is similar to that of the old. Therefore, the field populations measured in the survey reported in Chapter 4 are only around one half of the optimum.
On the basis of past experience (Kudratullaev et al., 1981) it would seem that a positive response in yield to increased plant populations of *G. barbadense* up to around 180,000 plants/ha could be expected in long staple cotton fields in Turkmenistan. An experiment using one long staple cotton cultivar, at one row spacing, at seven populations from 30,000 to 210,000 plants/ha, conducted over a number of seasons to re-test the response of the newer long staple cultivars to plant population is strongly recommended.

### 9.2 The reasons for low field populations

Although this thesis is concerned with low populations, the initial plant populations in government farms and in cooperative fields throughout Turkmenistan and the CIS are very high. This is because sowing rates are 100 – 120 kg/ha of seed (90% germination), compared to rates of 15-20 kg/ha in countries like the USA and Australia (Trives and Vaughan, 1998b). Rates are high because of the perception that soil crusting in the case of rain during April will prevent germination of cotton. The densely planted seed is said to have the combined energy to break the surface seal if planted very densely (Mr. Sopiev, Director, ARPEC, pers. comm. 2002). The use of fuzzy seed may also lead to clumps of seed forming when seed passes through the drill at sowing time. This may also lead to the practice of sowing amounts far greater than required (Trives and Vaughan, 1998b).

Whatever the reason for using these high sowing rates, it results in the need to thin plants to the required density. This is done by hand, using Turkmen and ‘Russian’ hoes.

How field populations end up at only 20-60,000 plants/ha, when they start at such a high density, was the subject of experiments undertaken in Chapter 6. The aim of understanding
why plant populations are so low in Turkmenistan was to develop recommendations that may improve cotton yields via manipulating field plant densities.

Two possible causes were considered, the effects of pests and diseases after emergence, and the effect of hand thinning which may not meet the target populations of 100,000 plants/m$^2$.

In the experiment conducted on the effect of thinning on field plant populations; and in fields inspected on government research stations (ARPEC and CRI); plant populations after emergence and prior to thinning were high, of the order of 320-400,000 plants/ha. It would appear that the low field populations (20-60,000 plants/ha) noted one to two months after planting were due to the inability of operators to thin plant stands to higher plant populations (see Chapter 6), rather than to any reduction in plant populations following early seedling death due to fungal pests or insects. Operators are also quite variable in their ability to thin cotton stands.

There was early insect damage by bean aphid Smynthurodes betae in the experiment on ‘early seedling death’ reported in Chapter 6 that was significant visually, but not in terms of reduced plant populations. It has also been established that early seedling losses may not have a significant effect on final yield if the surviving populations are near the optimum (Holman and Oosterhuis, 1999; Longer and Oosterhuis, 1999). This was the case in the experiment at ARPEC, in which the surviving population in all treatments exceeded 80,000 plants/ha and there was no significant effect on final yield (average of all treatments 2,919 kg/ha seed cotton), fibre quality (average of all treatments 4.7 micronaire, 0.88 ML, 1.10 UHML, 80.3 UI, 19.0 SFI, Pressley strength 7.97, GOT 38.7, 100 seed weight 10.1 g) or maturity (open bolls 18.6%, 53.0% and 80.1% 130 DAP, 140 DAP and 148DAP). However, as early insect attack may be a factor limiting plant populations under certain conditions, it
can be recommended as a precaution, that all cottonseed should be treated with the seed
dressing imidacloprid (commercial name ‘gauclo’) at the rate of 8.75 ml/kg seed. It may
further be recommended that experiments to investigate early seedling death due to insect or
fungal pathogens should be continued in Turkmenistan.

The role of fuzz or lint in inhibiting water uptake in cotton seed was elegantly demonstrated
in experiments conducted by Marani and Amirav (1970). Acid de-linting may considerably
improve cotton establishment in Turkmenistan. It improves germination both in the
laboratory and in the field (Christidis, 1936). These germination increases are often
accompanied by yield increases (MacDonald et al., 1947). Increased germination is
associated with removal of fuzz and also separation of chemically treated seeds into
‘sinkers’ and ‘floaters’ – the later having poorer viability and being removed in the
treatment process - and the control of bacterial and fungal diseases of the young cotton plant
(Hansford et al., 1933; MacDonald et al., 1947). Germination tests carried out on acid-
delinted ‘sinkers’ and floaters’ of seed of both *G. hirsutum* (Ahal 1) and *G. barbadense*
(Iolatan 5, Iolatan 97, 9938E) cultivars in Turkmenistan in 2002 confirm these findings for
Turkmen cotton cultivars (National Institute of Agricultural Botany, 2002).

The current system used in Turkmenistan and throughout Central Asia of planting seed at
high rates and then thinning using hand-held implements has been shown, in this thesis, to
result in plant populations that are variable and may be less than optimum. Even the five
best of 37 trained operators could not thin to 100,000 plants/ha, achieving an average of
only 78,000 plants/ha before the conduct of the experiment reported in Chapter 6, after a
week spent in a field in which the target population was 100,000 and which was adjacent to
an experimental field with the target population. In another experiment, a group of 20
operators achieved populations ranging between 40,000 and 120,000 plants/ha, even after
training. In the general mobilization that takes place each year to hand weed and thin the new crop, it is nearly impossible for operators to be trained and supervised.

9.3 The scale of responses to plant population

The effect of plant population on yield was considerable in the three experiments conducted with medium staple cotton, and higher than that reported in the literature (Heitholt, 1994; Bruyn et. al., 1989; Bridge et. al., 1973; Kumar, 1988; Gannaway et al., 1995; Fowler and Ray, 1977; Anastassiou-Lefkopoulou and Sotiriadis, 1984). These results are summarized in Table 5.17.

These considerable increases may be explained in part by the use of small stature cultivars in the experiments growing in the short season conditions prevailing in Turkmenistan, which are described in Chapter 3 (Bilbro, 1972; Verhalen and Williams, 1992). Ashgabat/Anau and other areas in Turkmenistan (crop in the field around 150-155 days) would be regarded as ‘short-season’ by Australian standards (crop in the field 180-190 days) and comparable to areas like Arkansas in the USA and Greece in Europe (Professor S. Galanopolou-Seneca, pers. comm. 2002).

The geometry of the cotton plant growing in Turkmenistan under conditions of low insect attack (low ‘tipping-out’ or production of lateral branches due to insect attack on branch terminals around the time of floral initiation) more closely resembles that of cotton genetically modified for insect resistance grown in Australia (Dr. G. Constable, CRI, Narrabri, pers. comm. 2003). In all experimental and elite seed fields used in the work described in this thesis, only a very few plants were found that were ‘tipped-out’, by minor damage due to green mirid (*Creatoniades dilutus* Stal). Natural predators ladybirds (genera
*Coccinella, Micraspis, Diomus* and lacewings (genus *Mallada*) were evident in experimental fields and spraying to control mirids was not necessary. Genetically modified cotton has been found to have a far greater response than conventional cotton to plant density increases in a similar range to that of the experiments conducted (J. Marshall, Cotton Seed Distributors, Narrabri, unpublished data). The large responses recorded in this thesis may thus be in part explained by the crop geometry of the Turkmen cultivars growing under conditions of low insect attack.

### 9.4 Utility of the COTMAN system in Turkmenistan

The research reported in this thesis was set within the phenological framework of the ‘COTMAN’ crop monitoring system described in Chapters 2 and 8. This allowed the relationship between treatments (plant population, row spacing, cultivars, irrigation) and crop maturity and yield, to be examined or characterized in terms of crop phenology.

Plant population treatments at ARPEC had differences in maturity characterized by COTMAN curves, but not at CRI. Irrigation treatments had differences in phenology, maturity and yield characterized by COTMAN curves at ARPEC, and phenological differences summarized at CRI.

On the other hand, a row spacing x cultivar x plant population experiment conducted using long staple cultivars at ARPEC Anau had a significant response in crop phenology to plant population, well described by a series of COTMAN curves, unrelated to treatment differences in either yield or maturity. However, there was no response to row spacing of any phenological character measured in this experiment (see Table 7.12). The COTMAN
curves for the row space treatments in this experiment, shown in Figure 7.1 in Chapter 7, reflect this lack of differences in phenology of plants at the two row spaces.

This leads to the tentative conclusion that light interception in both canopies was the same leading to the same pattern of growth being observed in both row treatment canopies. This contention is based on work reported on light interception in the canopy reported by Krieg (1992), Pettigrew et al. (1992), Peng and Kreig (1991) and Heitholt et al. (1992) and is supported by the work of Boquet and Coco (1993). Similar conclusions have been reported by Hoskinson et al. (1972) and Maas (1997). Yield differences in the row spacing x cultivar x plant population experiment can be attributed to different inter-plant spaces in different rows rather than a row effect per se. The fact that increasing row spacing from 60 to 90 cm decreased number of bolls per plant from 8 to 7 indicates increased stress on the individual plant at the greater row spacing where inter-plant spacing was reduced (Tyaminov, 1983; Jones and Wells, 1997; Hoskinson et al., 1972; Mass, 1997; Wanjura and Bilbro, 1977).

This is an example of how the COTMAN curve may have utility in preparing hypotheses to explain treatment differences in experiments, rather than simply characterizing them. It also illustrates how using a system like COTMAN to describe treatment differences in crop phenology may substitute detailed observations of the developing crop for the expensive and often unavailable equipment needed to measure light interception in the crop canopy. This makes it a valuable research tool in Turkmenistan and other Central Asian states with limited finances for research.

COTMAN ‘curves’ were developed for the medium staple cultivars Turkmenbashi 1 and Iolatan 7 and for the long staple cultivars Iolatan 5, Ashgabat 97 and 9938E for the first time in Turkmenistan from the field experiments described in this thesis. This in itself is an
important contribution to cotton breeding efforts in Turkmenistan in that it will allow
evaluation of new progeny from breeding schemes and introductions against the phenology
of standard types.

Further COTMAN ‘curves’ could be produced for the main cultivars used in Turkmenistan
and these used to monitor the growth of field cotton crops. The slope of curves (changes in
NAWF through the boll production part of the season) could also be used to compare the
growth and development of Turkmen cultivars to those developed in Arkansas, USA and
Greece where the COTMAN system is currently in use (see Chapter 8). More importantly,
they could be used to compare Turkmen cultivars such as Turkmenbashi 1 and Iolatan 7 to
determine if the trend towards early maturity has led to physiological cut-out too early in the
season.

COTMAN curves constructed based on experiments with Turkmenbashi 1 may also account
for the reports by its breeder, Dr. A. Babaev, that this cultivar can be planted up to three
weeks late in early May without any ‘yield penalty’ (Dr. A. Babaev, pers. comm., 2002).
Given the severe weed problems in some of the locations in which this cultivar is grown, it
may be possible to postpone planting of this cultivar by three weeks in order to germinate
weeds and then spray fields with glyphosate (widely available in Turkmenistan since 2001)
before planting.

The newly developed cultivar Ash 36 (118 days to cut-out), which has a maturity between
Turkmenbashi 1 (103 days to cut-out at 3 plants/m² or 100 days at 10 plants/m²) and the
standard cultivar 133 (130 days to cut-out) may be predicted to out-yield Turkmenbashi 1 as
it allows an extra two weeks of growth before cut-out. Initial harvests of this cultivar in trial
plots at ARPEC in 2002 confirmed this.
Interestingly, Figure 8.9 indicates that Iolatan 7 and Turkmenbashi 1 both ‘cut-out’ at the same time (around 103 DAP) if NAWF=5 is the criteria for physiological cut-out. This is clearly not the case for Iolatan 7, which continued to set fruit for a considerable period after this. This may indicate that NAWF=4 may be a more suitable criteria for cutout of *G. hirsutum* cultivars under Turkmen conditions, as it is in longer-season environments like Australia. In Greece, another environment somewhat milder than that of short-season Arkansas, the change from NAWF=5 to NAWF=4 is already under consideration (Professor S. Gallanopolou-Seneca, Thessaly University, Greece, pers. comm. 2002).

The target development curves generated by the COTMAN crop monitoring system are particularly responsive to drought (Bourland *et al*., 1997b). The COTMAN curves developed from the irrigation experiment reported in Chapter 7 were also responsive to water stress. This result establishes the utility of the COTMAN system under Turkmen conditions. COTMAN curves of new introductions or crosses from drought tolerance breeding programs could be compared with the curves for standard cultivars (S133, Turkmenbashi 1, Ashgabat 97) grown under drought conditions in introduction and breeding programs in Turkmenistan and also in other Central Asian states. Use of COTMAN curves in drought resistance breeding programmes could enable predictions to be made about the drought tolerance of prospective introductions.

It has been reported in recent literature that plant population may affect plant phenology without bringing about an increase in yield (Bednarz *et al*., 2000; Buehring and Dobbs, 2000); while at other times plant population affects yield as well as phenological characteristics of the cotton plant (Kerby *et al*., 1990a). Likewise, COTMAN TDCs may at times explain treatment differences in cotton yield and maturity by reference to phenology.
and at some times not. Even when they cannot be used to explain treatment differences, they may be used to make inferences about causes of treatment differences, for example in the row spacing x cultivar x population experiment. A summary of this is given below in Table 9.1.

**Table 9.1** Utility of COTMAN curves in explaining or providing hypotheses to explain treatment differences in yield, maturity and phenology in four experiments at two locations in Turkmenistan in 2002.

<table>
<thead>
<tr>
<th>Experiment and location</th>
<th>Utility of COTMAN curves in either explaining or inferring reasons for treatment differences in experiments</th>
<th>Yield</th>
<th>Maturity</th>
<th>Phenology</th>
<th>Causal hypotheses</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPxGap, ARPEC</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PPxIrr, CRI</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>RSxAxPP, ARPEC</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Irrigation, ARPEC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Whether plant population affected plant phenology in the experiments reported without affecting yield, or where plant population affected both plant phenology and yield, the COTMAN system enabled a large number of recordings of treatment differences in crop phenology to be represented concisely.

**9.5 Significance of the research undertaken in terms of broad objective of the thesis**
The aim of the research described in this thesis is to improve cotton production in Turkmenistan through optimizing plant population. The experiments indicate that very considerable yield increases could be obtained in Turkmenistan by using optimum plant populations in the nation’s cotton fields. This could mean that the current system of planting fuzzy seed at very high seeding rates by tractor followed by hand thinning could be replaced by a system of planting fuzzy seed at around 120,000 seeds/ha or 12 kg/ha (for cultivars like Turkmenbashı 1 and Iolatan 7) without any hand thinning being employed. The use of acid de-linted seed would improve seed placement and germination (MacDonald et. al., 1947; National Institute of Agricultural Botany, 2002) and the Government of Turkmenistan are already considering the purchase of an acid delinting plant (TACIS, 2002b).

If the local perception that high sowing rates are needed to overcome soil ‘capping’ early in the season proves true, these problems would have to be overcome by improved agronomic methods if lower seeding rates are to be used.

The experiment reported on effects of row spacing and plant populations on three *G. barbadense* cultivars at ARPEC, Anau also showed a significant effect of row spacing on yield of fiber and seed-cotton. Should it not be practical to change the current system of machine planting and hand thinning (an important and widespread task in a country such as Turkmenistan with considerable under-employment), changing the row spacing (a simple operation requiring only the movement of tynes on the tractor tool bar) can bring about the required changes in plant populations from sub-optimum to optimum.

For example, an inter-plant distance of 18.5cm in a 90cm row - this inter-plant distance has proven to be within the ability of experimental operators - leads to a plant population of 60,000 plants/ha. However, at a row spacing of 60 cm, this same inter-plant distance equates
to a plant population of 90,000 plants/ha. The fact that in the 2002 season a number of farmers in the Lebap Velayat of Turkmenistan started to use 60cm rows (Dr. I Yagmur, Deputy Director, CRI, Iolatan, pers. comm. 2002) could indicate that this is a viable method of increasing field plant populations without changing the current tractor sowing/hand thinning system. However, difficulties in row irrigation at 60 cm spacing may add a significant cost to this method of achieving higher field plant densities. Further experimentation on cost / benefits of a 60 cm row system may profitably be undertaken in Turkmenistan.

Another important research finding reported in this thesis is that three irrigations of 1 ML/ha may be as effective as the currently recommended 5 in producing a satisfactory cotton crop. As most areas of Turkmenistan receive their irrigation water from the Amu Darya River via the Karakum Canal, which crosses 1,000 km of desert, the potential benefits of reducing irrigation requirements by 40% are considerable.

Bearing in mind that a 25% increase in yield on 25% of the nations cotton fields (that is those fields where water supply and fertilizer are adequate, taken to be the 25% of the nation’s fields reflecting the ‘top five fields’ of the twenty surveyed in Ahal Valayat in 2001) would equate to US$16.5 million to the industry per year based on the US$260 million value of the 2001 crop (TACIS, 2002b), the use of optimum plant populations /row spaces in the cotton fields of Turkmenistan has a substantial potential for economic benefit to the farmers of that country.

Changing plant populations would require none of the structural changes involved in changes to irrigation frequencies (determined by the state) or supply of state subsidized and controlled fertilizers and therefore have the added advantage of being possible at little cost.
BIBLIOGRAPHY


Association of Official Seed Analysts (1983) Seed vigor testing handbook, Contribution No. 32 to the handbook on Seed Testing p63-64

Avtonomov A.A. and Blijina P.Y. (1968) Effectiveness of different depths and technique of ploughing against two types of chemical fertilizer application background, Jivotnovodstvo / Animal Husbandry Magazine No 5, 1968


Bakasov, A.Sh (1977) The yield of high populations of long staple varieties (results of 50 years activity regarding to breeding programs for long staple varieties in Turkmenistan), Scientific Reports of the Turkmen Scientific Research Institute of Seed Production and Breeding of Long Staple Varieties, Ashgabat 1977, No 15 pp 76-79

Bakasov, A.Sh. and Yagmurov, K.Y. (1974) Growth and development of long staple varieties considering the different plant populations, Scientific Reports of the Turkmen Scientific Research Institute of Seed Production and Breeding of Long Staple Varieties, Ashgabat 1974, No 12 pp 32-35


Bondada, R.B. (1994) Late-season canopy photosynthesis and foliar nitrogen fertilization of cotton (Gossypium hirsutum L.), PhD Dissertation University of Arkansas, Fayetteville, 1994


Fursov, V.N. (1961) Differentiation of plant population depending on soil fertility, J. Ag. of Turkmenistan No 1 pp 23-27


Guinn, G. (1982b) Abscisic acid and abscission of young cotton bolls in relation to water availability and boll load, Crop Sci. v 22 p580-583

Guinn, G. (1985b) Abscisic acid cut-out in cotton, Plant Physiology v 77 p16-20


Hearn, A.B. (1975) Response of cotton to nitrogen and water in a tropical environment. II. Date of last watering and rate of application of nitrogen fertilizer, J. Agric. Sci. (Cambridge) v 84 p419-430


Heitholt, J.J. (1994) Canopy characteristics associated with deficient and excessive cotton plant population densities, Crop Sci. 1994 v 34 no 5 p 1291-1297


Holliday, R. (1960b) Plant population and crop yield, FCA v 13 pp 159-167 and 247-254


Hutchinson, J.B. and Manning, H.L. (1945) The sea island cottons, Empire J. of Experimental Agriculture v 13 p 80-92

Hutchinson, J.B. (1962) The history and relationships of the world’s cottons, Endeavour v 21 p5-15
Huxley, P.A. (1964) Some effects of artificial shading on the growth of upland cotton seedlings, Empire Journal Cotton Growing Review v 41 p100-111


Jadhao, J.K.; Degaonkar, A.M.; and Narkhede (1993) Performance of hybrid cotton cultivars at different plant densities and nitrogen levels under rainfed conditions, Indian J. Agron. v 328 p 340-341


Kudratullaev, A.V. (1981) Methods of planting, plant population and yield J Ag of Turkmenistan, No 4 pp 7-9

Ministry of Agriculture Turkmen Scientific Institute of Agriculture and Water Management, Ashgabat, 1981 pp 7-9

Kumar, V. (1988) Response of late-sown cotton (Gossypium hirsutum L.) to dates of sowing and plant populations in the Nigerian savanna, Crop Research (Hisar) 1: 1, 58-68

Kurbangeldiev, S.B. (1985) About cotton populations, J. Ag. of Turkmenistan, No 4 pp 16-18


Michilini, F.J. (1958) The plastochron index in developmental studies of Xanthium italicum

Moretti American Journal of Botany v 45 p525-533

Ministry of Agriculture, Turkmenistan (2001) The objectives of national science in the implementation of Great Turkmenbashi’s improvements in agricultural production,
Proceedings of the National Conference Dedicated to the 10th year of Independence of Turkmenistan, Turkmen University of Agriculture, Ashgabat, 3rd October 2001


Mutchler, C.K.; McDowell, L.L. and Greer, J.D. (1985) Soil losses from cotton with conservation tillage, Transactions of the ASAE v 28 (1) p160-163,168


Oosterhuis, D.M. (1998) COTMAN Cotton management program, University of Arkansas, Division of Agriculture, CD ROM


Peacock, H.A.; Reid, J.T. and Hawkins, B.S. (1971) Cotton yield, stand and bolls per plant as influenced by seed class and row width, Crop Science v 11 p 743-747


Rejepov, O.; Artykov, P.; and Kolesov, O (1985) To develop agro-irrigation technique and methods of irrigation regime maintenance for cotton fields new and old introduced to irrigation that provide the yield of seed cotton 35-40 c/ha and develop anti soil erosion policy, Final report of the Turkmen Institute of Agriculture, Turkmen Scientific Institute of Agriculture and Water Management, Dashoguz 1985.


Rejepov, O.; Artykov, P.; and Kolesov, O (1985) To develop agro-irrigation technique and methods of irrigation regime maintenance for cotton fields new and old introduced to irrigation that provide the yield of seed cotton 35-40 c/ha and develop anti soil erosion policy in Final report of the Turkmen Institute of Agriculture, Dashoguz 1985.

Rejepov O.; Mammedov M.K.; Sakhatmuradov B.M.; and Ovezjanova G. (1991) Final report on the design of water saving technique for operational washing along the furrows of salted areas against the deep soil tillage background at Murgab Oasis, Land and Water Institute, Ashgabat 1991.


Schubert, A.M. (1975) Growth and development of the cotton fiber, PhD Thesis, Texas A&M University College, Station TX.


State Committee of Turkmenistan for Tourism and Sport, Turkmenistan (2000) Welcome to Turkmenistan, Press Voyage, Ashgabat 2000, p4


TACIS (2002a) Support to the Cotton Sector Project – Introduction to Cotton Classing, European Union’s TACIS Office Ashgabat April 2002


Weir, B.L. (1991) Narrow row means higher yields, Cotton Farming Special Issue v 96 p 8-9


