This section presents information on water relations and water management of banana and provides links to other sources of information.Banana (Musa spp.) is one of the most important tropical fruits. Ripe banana fruits are sugary and eaten raw; unripe fruits, called plantains, are cooked and provide a starchy food with nutritional value similar to potato. Total world production of banana is about 68.6 million tons of fresh fruit (FAOSTAT, 2001).

The cultivated banana is believed to have originated in the lowland, humid tropics in Southeast Asia and is mostly grown between 30�N and S of the equator. A mean temperature of about 27�C is optimal for growth. Minimum temperature for adequate growth is about 16�C, below which growth is checked and shooting delayed. Temperatures below 8�C for long periods cause serious damage. Maximum temperature for adequate growth is about 38�C, depending on humidity and the radiation intensity. Bananas are day-neutral in their response to daylength.

A humidity of at least 60 percent or more is preferable. Strong winds, greater than 4 m/sec, area major cause of crop loss due to the pseudostems being blown down. Under high wind conditions windbreaks are desirable.

Bananas can be grown on a wide range of soils provided they are fertile and well-drained. Stagnant water will cause diseases such as the Panama disease. The best soils are deep, well-drained loams with a high water holding capacity and humus content. Optimum pH is between 5 and 7. The demands for nitrogen and especially potash are high. Since the early stages of growth are critical for later development, nutrients must be ample at the time of planting and at the start of a ratoon crop. Short intervals between fertilizer applications, especially nitrogen, are recommended. Fertilizer requirements are 200 to 400 kg/ha N, 45 to 60 kg/ha P and 240 to 480 kg/ha K per year.

Banana is very sensitive to salinity and soils with an ECe of less than 1 mmho/ cm are required for good growth.

Banana, 2 to 9m tall, bears leaves on a pseudostem consisting of leaf stalks. The flowering stalk emerges (shooting) from the pseudostem and produces a hanging bunch of flowers. Fruits are formed on 'hands' with about 12 fingers; each bunch contains up to 150 fingers. After harvest the pseudostem is cut. The underground stem (corm or rhizome) bears several buds which, after sprouting, form new pseudostems, or so-called suckers. They are removed except for one or two which provide the ratoon crop.

Banana is normally multiplied vegetatively. Several types of suckers can be used. The development of the plant can be divided into three periods: vegetative, flowering and yield formation. The time from planting to shooting (vegetative) is about 7 to 9 months, but with lower temperatures at higher altitudes or in the subtropics, up to 18 months. The time from shooting to harvest (flowering and yield formation) is about 90 days. In tropical lowlands the time to harvest of the next ratoon crop is about 6 months. The number of ratoons varies. The average life of a commercial plantation can be from 3 to 20 years; with mechanical cultivation the economic life is often 4 to 6 years. Some varieties are replanted after each harvest.

Planting distances vary according to variety, climate, soil and management and are between 2 x 2 m and 5 x 5 m, corresponding to a density of 400 to 2500 plants/ha. On steep slopes contour planting is practised. The crop is sometimes interplanted or is used as a nurse crop for crops such as cocoa.

Following figure presents the development of banana (Champion, 1963)

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalBanana 1st yearStage length, days12090120� �60390� �March� �Mediterranean�Depletion Coefficient, p0.35>>0.350.35-�Root Depth, m0.80>>>>0.80-�Crop Coefficient, Kc0.5>>1.11.0-�Yield Response Factor, Ky1.2-1.35-�Banana 2nd yearStage length, days12006180 ��5365 ��February� �Mediterranean�Depletion Coefficient, p0.35>>0.350.35�Root Depth, m0.80>>>>0.8-�Crop Coefficient, Kc1.0>>1.21.1-�Yield Response Factor, Ky1.2-1.35�Being a long duration crop, the total water requirements of banana are high. Water requirements-per year vary between 1200 mm in the humid tropics to 2200 in the dry tropics. For rainfed production, average rainfall of 2000 to 2500 mm per year, well-distributed, is desirable, but banana often grows under less rainfall.

In relation to reference evapotranspiration (ETo) the maximum water requirements (ETm) can be determined with the crop coefficient (kc), or ETm = kc. ETo.

Following table presents monthly kc values of Banana for subtropical climateSubtropical climatekcJFMAMJJASONDFirst-year crop, March planting:Humid, light to mod. wind�Dry, strong wind-�---.65.5.6�.45.55.5.6�.65.7�.8.85�1.0.95�1.151.0�1.21.0�1.151.0�1.15Second with ratoon starting in February:Humid, light to mod. windDry strong wind1.0�1.15.8.7.75.75.7�.7.7�.75.75.9.9�1.11.051.251.051.251.051.251.0�1.21.0�1.2Following table presents monthly kc values of Banana for tropical climateTropical climateMonths following planting:123456789101112131415.4.4.45.5.6.7.851.01.11.1.9.8.8.951.05�suckeringshootingharvestingThe relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

Banana requires an ample and frequent supply of water; water deficits adversely affect crop growth and yields. The establishment period and the early phase of the vegetative period (0-1) determine the potential for growth and fruiting and an adequate water and sufficient nutrient supply is essential during this period. Water deficits in the vegetative period (1) affect the rate of leaf development, which in turn can influence the number of flowers in addition to the number of hands and bunch production

The flowering period (2) starts at flower differentiation, although vegetative development can still continue. Water deficits in this period limit leaf growth and number of fruits.

Water deficits in the yield formation period (3) affect both the fruit size and quality (poorly filled fingers). A reduced leaf area will reduce the rate of fruit filling; this leads, at harvest time, to bunches being older than they appear to be and consequently the fruits are liable to premature ripening during storage

The ratio between relative yield decrease and relative evapotranspiration deficit (ky) is 1.2 to 1.35, with little difference between different growth periods.

Regular water supply under irrigation over the total growing season as compared to rainfed production with seasonal differences in water supply produces taller plants, with greater leaf area, and results in earlier shooting and higher yields. Interval between irrigation has a pronounced effect on yields, with higher yields being achieved when intervals are kept short. Under conditions of limited water supply, total production will be higher when full crop water requirements are met over a limited area than when crop water requirements are partially met over an extended area.The banana plant has a sparse, shallow root system. Most feeding roots are spread laterally near the surface. Rooting depth will generally not exceed 0.75 m. In general 100 percent of the water is obtained from the first 0. 5 to 0.8 m soil depth (D = 0. 5-0.8 m) with 60 percent from the first 0.3 m. With maximum evapotranspiration (ETm) of 5 to 6 mm/day, a 35 percent depletion of the total available soil water should not be exceeded (p = 0.35).Since a depletion of total available soil water in excess of about 35 percent during the total growing period is harmful to growth and fruit production, frequent irrigation is important. The irrigation interval will depend on ETm and the soil water holding capacity in the rooting depth and may vary from 3 days under high evaporative conditions and light soils up to 15 days under low evaporative conditions and high water retaining soils. When rainfall and irrigation water is limited, it is advantageous to reduce the depth of each water application rather than to extend the irrigation interval.Overhead sprinkler systems with small application at frequent intervals are commonly used in commercial banana plantations. Surface irrigation methods include the basin, furrow or trench irrigation systems. The trench system also serves as a drain during the rainy periods. Also drip irrigation is used; with drip irrigation under conditions of high evaporation, low rainfall and particularly when irrigation water contains even a small amount of salt, accumulation of salts at the boundary of wet and dry soil area will occur. Under such conditions leaching will often be needed since banana plants are highly salt-sensitive and damage to the crop can otherwise easily occur.Yields can vary enormously, Under poor management yields are usually highest for the planted (first) crop and decline for the ratoon crops. Under intensive management with correct desuckering and control of pests and. diseases, yields from the first ratoons are usually higher than for the plant crop. Good commercial yields of banana are in the range of 40 to 60 ton/ha. The water utilization efficiency for harvested yield (Ey) of fruits, containing about 70 percent moisture, is 2.5 to 4 kg/m3 for the plant crop and 3.5

to 6 kg/m3 for ratoon crops. � � � � � � � � � � � � � � � � � � � ��� �

This section presents information on water relations and water management of tobacco and provides links to other sources of information.Tobacco (Nicotiana tabacum) is believed to have originated from South America. Present world production is about 6.3 million tons of leaves from 4.2 million ha. (FAOSTAT, 2001).

The crop can be broadly divided according to the method of curing the leaves flue, fire, air or sun-cured. In general, the dark-coloured air and fire-cured tobacco is used for pipe and cigar tobacco, whereas the light-coloured flue and sun-cured is used for cigarette tobacco.

Tobacco is grown under a wide range of climates but requires a frost-free period of 90 to 120 days from transplanting to last harvest of leaves. Optimum mean daily temperature for growth is between 20 and 30�C. A dry period is required for ripening and harvest of the leaves. Excess rainfall results in thin, lightweight leaves. Sun-cured or oriental tobacco requires a relatively dry climate to develop its full aroma. Except for some short-day varieties, cultivated tobacco is day-neutral in its response to flowering.

A light, sandy soil is required for flue-cured, light tobacco. Air-cured, dark tobacco is grown on silty loam to clay loam soils, while fire-cured and air-cured, light tobacco is mostly grown on medium textured soils. The crop is sensitive to waterlogging and demands well-aerated and drained soils. The optimum pH ranges from 5 to 6.5. Quality of the leaves is affected by soil salinity. Depending on the type of tobacco, fertilizer requirements vary and in general are 40 to 80 kg/ha N, 30 to 90 kg/ha P and 50 to 110 kg/ha K.

Tobacco is sown on seed beds and is transplanted 40 to 60 days after sowing when the plants are about 15cm tall. During the first weeks the seedbeds are often covered to protect the young seedlings against unfavourable weather. Spacing after transplantation caries with variety and is generally between 1.2 to 0.9 x 0.9 to 0.6 m. Crop rotation after one or two seasons is recommended with crops such as grass, sorghum, millet and maize that are not susceptible to root eelworm.

To produce high value leaves, topping (removal of flower buds) and desuckering (removal of side shoots) is often practised. Time and height of topping depends on the type of tobacco but is us�al1y done when 10 percent of the plants have their buds in flower.Stages of DevelopmentPlant dateRegionCrop characteristicInitialCrop DevelopmentMid-seasonLateTotalStage length, days20303030110Depletion Coefficient, p0.4>>0.50.65-Root Depth, m0.25>>>>0.8-Crop Coefficient, Kc0.5>>1.10.8-Yield Response Factor, Ky0.21.00.50.50.9The water requirements (ETm) for maximum yield vary with climate and length of growing period from 400 to 600mm. During the first weeks after emergence in the seedbed the seedlings require 3 to 5 litres/m2�daily. After 30 to 40 days the seedlings receive less water so as to obtain a more robust plant. After 40 to 60 days, the seedlings are transplanted and the crop is harvested 90 to 120 days after transplanting. The period of maximum water requirements occurs 50 to 70 days after transplanting and is followed by a decrease in water requirements.

The crop coefficient (kc) relating crop water requirements (ETm) to reference evapotranspiration (ETo) for the different development stages after transplanting are: during the initial stage 0.3-0.4 (10 days), the development stage 0.7-0.8 (20 to 30 days), the mid-season stage 1.0-1.2 (30 to 35 days), during the late-season stage 0.9-1.0 (30 to 40 days) and at harvest 0. 75-0.85.Following figure shows growth period in tobacco (Lucas)

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

The water regimes from which a full crop of tobacco can be obtained vary from stored soil water, rainfall, supplemental irrigation or full irrigation. Careful water scheduling is required because too frequent irrigation damages the crop. Water deficits in certain periods may increase yields and it is recommended practice to subject seedlings during the establishment period (0) prior to transplanting to a period of moderate water deficit to increase their drought resistance. Also, moderate water deficits during the early vegetative period (1a) may enhance root development. Moderate water deficits during the first 20 to 30 days after transplanting have little effect on final yield but cause temporary retarded growth; however, the crop recovers rapidly with subsequent irrigations. In most cases, final yields may be larger compared to a crop receiving full irrigation throughout this growth period (1a).

Water deficits during the mid-vegetative period (rapid growth, 1b) result in reduced growth and smaller leaves. Severe water deficits during the yield formation and ripening periods (3 and 4) affect leaf weight and chemical composition which in turn affects the fire-holding capacity. However, a mild water deficit during ripening (4) is desirable to restrict growth of new young leaves.

Excess water results in leaves of low quality. Heavy rain or irrigation may cause 'wilting', 'wet feet' or 'drowning'. Waterlogging for two or more days generally severely damages the crop and may kill the plants.

To obtain maximum total production under limited water supply, management should be directed towards increasing the area and partially meeting the crop water requirements rather than meeting full crop water requirements over a limited area.Tobacco has a well-developed tap root with extensive horizontal lateral roots. Normally 75 percent of the water uptake occurs over the first 0.3m.and 100 percent over the first 0.5 to 1.0 m (D = 0.5-1.0 m). Root development is enhanced by withholding water supply during early vegetative period (1a). Also topping and desuckering will favour root development. Full rooting depth is reached some 40 to 50 days after transplanting. Under conditions when ETm is 5 to 6mm/day, water uptake will be affected when 50 to 60 percent of the total available soil water has been depleted (p = o.6).Water must be supplied daily to the young seedlings in the seedbed (0) even when evapotranspiration is moderate. At the end of the seedbed period (0) water is withheld for a few days. Immediately before and during transplanting water is supplied to the plants individually to help them through the first weeks after transplanting. During the rapid growth period (1b), water should be supplied frequently. During the early yield formation period (3), at flowering, few deep irrigations may be sufficient to obtain optimum yields of high quality. When water is limited, water should be applied at transplanting, during the period of rapid growth (1b), and during the early yield formation period (3).Irrigation Methods

Surface and sprinkler irrigation are mostly practised. The quality of the water is important in selecting the most suitable irrigation method, e.g. sprinkler irrigation should be avoided when only low quality water is available.Normally 18 to 22 leaves are harvested with 2 to 3 leaves per week for 30 to 50 days. Occasionally, when half the leaves have been harvested and if the remaining leaves show a uniform ripening, the whole plant is harvested, thus saving labour. Good yields under commercial production with adequate water supply are in the range of 2 to 2.5 ton/ha of leaves. The water utilization efficiency for harvested yield (Ey) for cured leaves containing about 10 percent moisture is 0.4 to 0.6 kg/m3.Irrigation practices together with cultivation practices, e.g. topping, and soil fertility affect leaf quality. Nicotine content of the leaf is generally 1.5 to 2.5 percent of dry leaf matter for the flue-cured tobacco and 3 to 4 percent for the air-cured tobacco. Tobacco grown under dry conditions frequently has a dark, small leaf which is dull in colour and lacks elasticity. However, it has a high nicotine content. Under adequate water supply the leaves are thinner and more elastic, and also the colour is improved, while the nicotine content is optimal. Over-irrigation, particularly during the latter part of the total growing period results in inferior leaf quality. ��� � This section presents information on water relations and water management of maize and provides links to other sources of information.Maize (Zea Mays) originates in the Andean region of Central America. It is one of the most important cereals both for human and animal consumption and is grown for grain and forage. Present world production is about 594 million tons grain from about 139 million ha (FAOSTAT, 2000).

The crop is grown in climates ranging from temperate to tropic during the period when mean daily temperatures are above 15�C and frost-free. Adaptability of varieties in different climates varies widely. Successful cultivation markedly depends on the right choice of varieties so that the length of growing period of the crop matches the length of the growing season and the purpose for which the crop is to be grown. Variety selection trials to identify the best suitable varieties for given areas are frequently necessary.

When mean daily temperatures during the growing season are greater than 20�C, early grain varieties take 80 to 110 days and medium varieties 110 to 140 days to mature. When grown as a vegetable, these varieties are 15 to 20 days shorter. When mean daily temperatures are below 20�C, there is an extension in days to maturity of 10 to 20 days for each 0.5�C decrease depending on variety, and at 1.5�C the maize grain crop takes 200 to 300 days to mature. With mean daily temperature of 10 to 15�C maize is mostly grown as a forage crop because of the problem of seed set and grain maturity under cool conditions. For germination the lowest mean daily temperature is about 10�C, with 18 to 20�C being optimum. The crop is very sensitive to frost, particularly in the seedling stage but it tolerates hot and dry atmospheric conditions so long as sufficient water is available to the plant and temperatures are below 45�C. Temperature requirements, expressed as sum of mean daily temperatures, for medium varieties are 2500 to 3000 degree days, while early varieties require about 1800 and late varieties 3700 or more degree days.

In respect of daylength, maize is considered to be either a day-neutral or a short-day plant. The growth of maize is very responsive to radiation. However, five or six leaves near and above the cob are the source of assimilation for grain filling and light must penetrate to these leaves. For optimum light interception, for grain production, the density index (number of plants per ha/row spacing) varies but on average it is about 150 for the large late varieties and about 500 for the small early varieties. Sowing methods and spacing vary, and fertility and water are decisive factors in choosing the optimum density in relation to light interception and highest yields. Plant population varies from 20000 to 30000 plants per ha for the large late varieties to 50000 to 80000 for small early varieties. Spacing between rows varies between 0.6 and 1 m. Sowing depth is 5 to 7 cm with one or more seeds per sowing point. When grown for forage, plant population is 50 percent higher.

The plant does well on most soils but less so on very heavy dense clay and very sandy soils. The soil should preferably be well-aerated and well-drained as the crop is susceptible to waterlogging. The fertility demands for grain maize are relatively high and amount, for high-producing varieties, up to about 200 kg/ha N, 50 to 80 kg/ha P and 60 to 100 kg/ha K. In general the crop can be grown continuously as long as soil fertility is maintained.

Maize is moderately sensitive to salinity. Yield decrease under increasing soil salinity is: 0% at ECe 1.7 mmhos/cm, 10% at 2.5, 25% at 3.8, 50% at 5.9 and 100% at ECe 10 mmhos/cm.The graph below depicts the crop stages of maize, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop DevelopmentMid-seasonLateTotalStage length,�days30252020303030504035354040406045404050505040303030303050180140125125150150170AprilDec/JanJuneOct./DecAprilAprilAprilEast Africa (alt.)Arid Climate (alt.)Nigeria (humid)India (dry, cool)Spain (spr, sum)Calif.Idaho, USADepletion Coefficient, p0.500.500.500.80-Root Depth, m0.30>>>>1.00-Crop Coefficient, Kc0.30>>1.20.5-Yield Response Factor, Ky0.400.401.300.501.25Stages of DevelopmentCrop characteristicInitialCrop DevelopmentMid-season�LateTotalStage length, days25404035135Depletion Coefficient, p0.500.500.500.80-Root Depth, m0.30>>>>1.00-Crop Coefficient, Kc0.30>>1.20.5-Yield Response Factor, Ky0.401.0.401.300.501.25Maize is an efficient user of water in terms of total dry matter production and among cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain crop requires between 500 and 800 mm of water depending on climate. To this, water losses during conveyance and application must be added. The crop factor (kc) relating water requirements (ETm) to reference evapotranspiration (ETo) for different crop growth stages of grain maize is for the initial stage 0.3-0.5 (15 to 30 days), the development stage 0.7-0.85 (30 to 45 days) the mid-season stage 1.05-1.2 (30 to 45 days), during the late season stage 0.8-0.9 (10 to 30 days), and at harvest 0.55-0.6.This schematic graph shows the growth periods of maize.

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Frequency and depth of irrigation and rain has a pronounced effect on grain yield. Maize appears relatively tolerant to water deficits during the vegetative (1) and ripening (4) periods. Greatest decrease in grain yields is caused by water deficits during the flowering period (2) including tasselling and silking and pollination, due mainly to a reduction in grain number per cob. This effect is less pronounced when in the preceding vegetative period (1) the plant has suffered water deficits. Severe water deficits during the flowering period (2), particularly at the time of silking and pollination, may result in little or no grain yield due to silk drying. Water deficits during the yield formation period (3) may lead to reduced yield due to a reduction in grain size. Water deficit during the ripening period (4) has little effect on grain yield.

The effect of limited water on maize grain yield is considerable and careful control of frequency and depth of irrigation is required to optimize yields under conditions of water shortage. Where water supply is limited it may therefore be advantageous to meet, as far as possible, full water requirements (ETm) so as to achieve near maximum yield from a limited acreage rather than to spread the limited water over a larger acreage.

Maize flourishes on well-drained soils and waterlogging should be avoided, particularly during the flowering (2) and yield formation (3) periods. Waterlogging during flowering (2) can reduce grain yields by 50 percent or more.When evaporative conditions correspond to ETm of 5 to 6 mm/day, soil water depletion up to about 55 percent of available soil water (Sa) has a small effect on yield (p = 0.55). To enhance rapid and deep root growth a somewhat greater depletion during early growth periods can be advantageous. Depletion of 80 percent or more may be allowed during the ripening period.

Although in deep soils the roots may reach a depth of 2 m, the highly branched system is located in the upper 0.8 to 1 m and about 80 percent of the soil water uptake occurs from this depth. Normally 100 percent of the water is taken up from the first 1 to 1.7 m soil depth (D = 1 to 1.7 m). Depth and rate of root growth is, however, greatly affected by rainfall pattern and irrigation practices adopted. In addition to soil water and nutrient status, root development is strongly influenced by textural and structural stratification, salts and water table.To obtain a good stand and rapid root development, the root zone should, where feasible, be wetted at or soon after sowing. Taking into account the level of ETm, to meet full water requirements, the water depletion level is about 40 percent in the establishment period (0), between 55 and 65 percent during periods 1, 2 and 3, and up to 80 percent during the ripening period (4).Where rainfall is low and irrigation water supply is restricted, irrigation scheduling should be based on avoiding water deficits during the flowering period (2) followed by yield formation period (3). When a severe water deficit during the flowering period (2) is unavoidable, water may be saved by reducing supply during the vegetative period (1) as well as during the yield formation period (3) without incurring additional yield losses.Under conditions of marginal rainfall and limited irrigation water supply, the number of possible irrigation applications may vary between 2 and 5. A suggested timing of these irrigation applications is given below. To obtain a good stand and proper root development, the potential root zone should be wet either from rainfall or irrigation prior or soon after sowing.

Under irrigation a good commercial grain yield is 6 to 9 ton/ha (10 to 13 percent moisture). The water utilization efficiency for harvested yield (Ey) for grain varies then between 0.8 and 1.6 kg/m3. � � � � � � � � � � � � � � � � � � � ��� � This section presents information on water relations and water management of sorghum and provides links to other sources of information.Sorghum (Sorghum bicolor) appears to have been domesticated in Ethiopia about 5000 years ago. Present world production is about 58 million tons grain from 42.6 million ha. (FAOSTAT, 2001).

Sorghum has a number of features which make it a drought-resistant crop. It is extensively grown under rainfed conditions for grain and forage production. In dry areas with low and/or erratic rainfall the crop can respond very favourably to supplemental irrigation. However, considerable differences exist amongst varieties in their response to irrigation and those that are considered very drought-resistant respond slightly while others produce high yields under irrigation but are poor yielding when water is limiting. Temperature is an important factor in variety selection. Optimum temperatures for high producing varieties are over 25�C but some varieties are adapted to lower temperatures and produce acceptable yields. When mean daily temperatures during the growing season are greater than 20�C, early grain varieties take 90 to 110 days and medium varieties 110 to 140 days to mature. When mean daily temperatures are below 20�C, there is an extension of about 10 to 20 days in the growing period for each 0.5�C decrease in temperature, depending on variety, and at 15�C a sorghum grain crop would take 250 to 300 days to mature. With mean daily temperatures in the range of 10 to 15�C, the sorghum crop can only be grown as a forage crop because of the problems with seed set and grain maturity under cool conditions. Low temperatures (<15�C) during flowering and yield formation, and high temperatures (>35�C) lead to poor seed set, problems with ripening and reduced yields.

For optimum light interception the density index (plants per ha s row spacing) is about 3000 when adequate water and fertilizers are available (100 000 to 150 000 plants per ha). In areas where water (rainfall + irrigation) is in short supply, the greater the shortage, the greater is the advantage of wider spacing. Sorghum is a. short-day plant but day-neutral varieties exist.

The crop does well on most soils but better so in light to medium textured soils. The soil should preferably be well-aerated and well-drained. Sorghum is relatively tolerant to short periods of waterlogging. The fertilizer requirements are up to 180kg/ha N, 20 to 45 kg/ha P and 35 to 80 kg/ha K.

Sorghum is moderately tolerant to soil salinity. Yield decrease due to soil salinity under irrigation is: 0% at ECe 4 mmhos/cm, 10% at 5.1, 25% at 7.2, 50% at 11 and 100% at ECe 18 mmhos/cm.

The graph below depicts the crop stages of sorghum, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalSorghum-grainStage length, days202035354045 �3030130145 ��May/JuneMarch/April �USA, Pakis.,Med. Arid RegionDepletion Coefficient, p0.6>>0.50.80.55�Root Depth, m0.30>>>>1.4-�Crop Coefficient, Kc0.7>>1.0-1.150.55-�Yield Response Factor, Ky0.20.55450.20.9�Sorghum-sweetStage length, days202035354045 �3030130145 ��May/JuneMarch/April �USA, Pakis.,Med. Arid RegionDepletion Coefficient, p----0.5�Root Depth, m----1.0-2.0�Crop Coefficient, Kc0.7>>1.21.05-�Yield Response Factor, Ky-----�For high production crop water requirements (ETm) of 110 to 130 day sorghum are between 450 and 650 mm depending on the climate; to this the losses during con-veyance and application must be added. The crop coefficient (kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is: during the initial stage 0.4 (20 to 25 days), the development stage 0.7-0.75 (30 to 40 days), the mid-season stage 1.0-1. 15 (40 to 45 days), the late season stage 0.75-0.8 (30 days) and at harvest 0.5-0.55.Following table presents the growth periods of sorghum.Crop stageDays0Establishment, from sowing to head initiation15-201Vegetative, from head initiation to head emergence20-302Flowering, from emergence to seed set15-203Yield formation, from seed set to physiological maturity35-404Ripening, from physiological maturity to harvest10-15Total95-125The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Sorghum is relatively more drought-resistant than many other crops, e. g. maize. This is due to an extensive root system, effective control of evapotranspiration and stomata with an ability to recover rapidly after periods of water stress, and an ability to withstand desiccation. Further, where the growing season is long, the tillering varieties are able to recover to a certain extent from water deficits in the earlier growth periods by forming additional head-bearing tillers. Severe water deficits during the flowering period (2) cause pollination failure or headblast. The resulting yield reduction can be partly offset by additional head-bearing tillers.

Sorghum shows a high degree of flexibility toward depth and frequency of water supply because of its drought resistance characteristics. When water supply is limited it may be advantageous to spread available water over a larger area. While yield per unit area will be reduced, water utilization efficiency for yield will be greater resulting in higher overall production in relation to volume of water supplied. The timing of supply should aim at reducing water deficits to a minimum during the establishment (0), flowering, (2) and early yield formation (early 3) periods.The primary root system, with little branching, grows rapidly in deep soils to 1 to 1.5m. The secondary system starts several weeks after emergence and extends rapidly up to 2m, depending on depth of soil wetting. The maximum depth is generally reached at the time of heading. In deep soils the extensive root system allows additional flexibility in irrigation scheduling. Depending on depth and frequency of irrigation, 60 percent (less frequent) to 90 percent (frequent) of the water uptake occurs from the first metre of soil depth. Normally, when sorghum is full grown, 100 percent of the water is extracted from the first 1 to 2m (D = 1-2m). Under conditions when ETm is 5 to 6 mm/day, about 55 percent of the total available soil water can be depleted without reducing water uptake (p = 0.55). During ripening (4) 80 percent can be depleted.Where rainfall is not sufficient and irrigation water supply is restricted, irrigation to attain optimum production should be based on avoiding water deficits during the periods of peak water use from flowering (2) to early yield formation period (3). Where water supply will be limited during the flowering period, water savings can be made without causing additional heavy yield losses by reducing water supply during the vegetative (1), late yield formation (late 3) and ripening period (4).

The number of irrigations normally varies between one and four, depending on climatic conditions, and soil texture. The greatest water utilization efficiency will be obtained when these irrigations are well-timed in relation to the sensitivity of the crop to water deficits.

Irrigation is mostly by surface (border, basin or corrugation) method.A good yield under irrigation is 3.5 to 5ton/ha (12 to 15 percent moisture). The water utilization efficiency for harvested yield (Ey) for grain is between 0.6 and 1.0 kg/m3. Grain yield under spate irrigation with little or no rainfall, a total growing period of 90 days with ETm = 425 to 450 mm and net depth applied of about 300 mm, is about 800 kg/ha with a maximum of 1300 kg/ha. ��� �

//This section presents information on water relations and water management of sorghum and provides links to other sources of information.Sorghum (Sorghum bicolor) appears to have been domesticated in Ethiopia about 5000 years ago. Present world production is about 58 million tons grain from 42.6 million ha. (FAOSTAT, 2001).

Sorghum has a number of features which make it a drought-resistant crop. It is extensively grown under rainfed conditions for grain and forage production. In dry areas with low and/or erratic rainfall the crop can respond very favourably to supplemental irrigation. However, considerable differences exist amongst varieties in their response to irrigation and those that are considered very drought-resistant respond slightly while others produce high yields under irrigation but are poor yielding when water is limiting. Temperature is an important factor in variety selection. Optimum temperatures for high producing varieties are over 25�C but some varieties are adapted to lower temperatures and produce acceptable yields. When mean daily temperatures during the growing season are greater than 20�C, early grain varieties take 90 to 110 days and medium varieties 110 to 140 days to mature. When mean daily temperatures are below 20�C, there is an extension of about 10 to 20 days in the growing period for each 0.5�C decrease in temperature, depending on variety, and at 15�C a sorghum grain crop would take 250 to 300 days to mature. With mean daily temperatures in the range of 10 to 15�C, the sorghum crop can only be grown as a forage crop because of the problems with seed set and grain maturity under cool conditions. Low temperatures (<15�C) during flowering and yield formation, and high temperatures (>35�C) lead to poor seed set, problems with ripening and reduced yields.

For optimum light interception the density index (plants per ha s row spacing) is about 3000 when adequate water and fertilizers are available (100 000 to 150 000 plants per ha). In areas where water (rainfall + irrigation) is in short supply, the greater the shortage, the greater is the advantage of wider spacing. Sorghum is a. short-day plant but day-neutral varieties exist.

The crop does well on most soils but better so in light to medium textured soils. The soil should preferably be well-aerated and well-drained. Sorghum is relatively tolerant to short periods of waterlogging. The fertilizer requirements are up to 180kg/ha N, 20 to 45 kg/ha P and 35 to 80 kg/ha K.

Sorghum is moderately tolerant to soil salinity. Yield decrease due to soil salinity under irrigation is: 0% at ECe 4 mmhos/cm, 10% at 5.1, 25% at 7.2, 50% at 11 and 100% at ECe 18 mmhos/cm.

The graph below depicts the crop stages of sorghum, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalSorghum-grainStage length, days202035354045 �3030130145 ��May/JuneMarch/April �USA, Pakis.,Med. Arid RegionDepletion

Coefficient, p0.6>>0.50.80.55�Root Depth, m0.30>>>>1.4-�Crop Coefficient, Kc0.7>>1.0-1.150.55-�Yield Response Factor, Ky0.20.55450.20.9�Sorghum-sweetStage length, days202035354045 �3030130145 ��May/JuneMarch/April �USA, Pakis.,Med. Arid RegionDepletion Coefficient, p----0.5�Root Depth, m----1.0-2.0�Crop Coefficient, Kc0.7>>1.21.05-�Yield Response Factor, Ky-----�For high production crop water requirements (ETm) of 110 to 130 day sorghum are between 450 and 650 mm depending on the climate; to this the losses during con-veyance and application must be added. The crop coefficient (kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is: during the initial stage 0.4 (20 to 25 days), the development stage 0.7-0.75 (30 to 40 days), the mid-season stage 1.0-1. 15 (40 to 45 days), the late season stage 0.75-0.8 (30 days) and at harvest 0.5-0.55.Following table presents the growth periods of sorghum.Crop stageDays0Establishment, from sowing to head initiation15-201Vegetative, from head initiation to head emergence20-302Flowering, from emergence to seed set15-203Yield formation, from seed set to physiological maturity35-404Ripening, from physiological maturity to harvest10-15Total95-125The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Sorghum is relatively more drought-resistant than many other crops, e. g. maize. This is due to an extensive root system, effective control of evapotranspiration and stomata with an ability to recover rapidly after periods of water stress, and an ability to withstand desiccation. Further, where the growing season is long, the tillering varieties are able to recover to a certain extent from water deficits in the earlier growth periods by forming additional head-bearing tillers. Severe water deficits during the flowering period (2) cause pollination failure or headblast. The resulting yield reduction can be partly offset by additional head-bearing tillers.

Sorghum shows a high degree of flexibility toward depth and frequency of water supply because of its drought resistance characteristics. When water supply is limited it may be advantageous to spread available water over a larger area. While yield per unit area will be reduced, water utilization efficiency for yield will be greater resulting in higher overall production in relation to volume of water supplied. The timing of supply should aim at reducing water deficits to a minimum during the establishment (0), flowering, (2) and early yield formation (early 3) periods.The primary root system, with little branching, grows rapidly in deep soils to 1 to 1.5m. The secondary system starts several weeks after emergence and extends rapidly up to 2m, depending on depth of soil wetting. The maximum depth is generally reached at the time of heading. In deep soils the extensive root system allows additional flexibility in irrigation scheduling. Depending on depth and frequency of irrigation, 60 percent (less frequent) to 90 percent (frequent) of the water uptake occurs from the first metre of soil depth. Normally, when sorghum is full grown, 100 percent of the water is extracted from the first 1 to 2m (D = 1-2m). Under conditions when ETm is 5 to 6 mm/day, about 55 percent of the total available soil water can be depleted without reducing water uptake (p = 0.55). During ripening (4) 80 percent can be depleted.Where rainfall is not sufficient and irrigation water supply is restricted, irrigation to attain optimum production should be based on avoiding water deficits during the periods of peak water use from flowering (2) to early yield formation period (3). Where water supply will be limited during the flowering period, water savings can be made without causing additional heavy yield losses by reducing water supply during the vegetative (1), late yield formation (late 3) and ripening period (4).

The number of irrigations normally varies between one and four, depending on climatic conditions, and soil texture. The greatest water utilization efficiency will be obtained when these irrigations are well-timed in relation to the sensitivity of the crop to water deficits.

Irrigation is mostly by surface (border, basin or corrugation) method.A good yield under irrigation is 3.5 to 5ton/ha (12 to 15 percent moisture). The water utilization efficiency for harvested yield (Ey) for grain is between 0.6 and 1.0 kg/m3. Grain yield under spate irrigation with little or no rainfall, a total growing period of 90 days with ETm = 425 to 450 mm and net depth applied of about 300 mm, is about 800 kg/ha with a maximum of 1300 kg/ha. ��� � This section presents information on water relations and water management of wheat and provides links to other sources of information.Bread and durum wheat (Triticum aestivum and T. turgidum) were domesticated in the Near and Middle East. Present world production is about 582.7 million tons from 213.8 million ha.(FAOSTAT, 2001).

The crop is grown as a rainfed crop in the temperate climates, in the sub-tropics with winter rainfall, in the tropics near the equator, in the highlands with altitudes of more than 1500 m and in the tropics away from the equator where the rainy season is long and where the crop is grown as a winter crop.

Wheat is grown under irrigation in the tropics either in the highlands near the equator and in the lowlands away from the equator. In the subtropics with summer rainfall the crop is grown under irrigation in the winter months. In the subtropics with winter rainfall it is grown under supplemental irrigation.

The length of the total growing period of spring wheat ranges from 100 to 130 days while winter wheat needs about 180 to 250 days to mature. Daylength and temperature requirements are key factors in variety selection. Varieties can be grouped as winter or spring types according to chilling requirements, winter hardiness and daylength sensitivity. Winter wheat requires a cold period or chilling (vernalization) during early growth for normal heading under long days. Winter wheat in its early stages of development exhibits a strong resistance to frost, down to - 20�C. The resistance is lost in the active growth period in spring and during head development and flowering periods frost may lead to head sterility. Because of this sometimes more damage is done to the winter crop by spring frost than by winter frost.

In areas of severe winters, cold winds and little snow, spring wheat varieties are grown. Spring wheat does not require chilling for heading and it is day-neutral. However, it is also sensitive to frost. For winter and spring wheat minimum daily temperature for measurable growth is about 5�C. Mean daily temperature for optimum growth and tillering is between 15 and 20�C. Occurrence of (spring) frost is an important factor in selection of sowing date. A dry, warm ripening period of 18�C or more is preferred. Mean daily temperatures of less than 10 to 12�C during the growing season make wheat a hazardous crop. Knowledge of genetic characteristics and particularly the growth and development pattern of wheat varieties is essential for meeting the combination of various climatic requirements for growth development and yield formation.

The crop can be grown on a wide range of soils but medium textures are preferred. Peaty soils containing high sodium, magnesium or iron should be avoided. The optimum pH ranges from 6 to 8. For good yields the fertilizer requirements are up to 150 kg/ha N, 35 to 45 kg/ha P and 25 to 50 kg/ha K.

Wheat is relatively tolerant to a high groundwater table; for sandy loam to silt loam a depth of groundwater of 0.6 to 0.8 m can usually be tolerated, and for clay 0.8 to 1 m. For short periods the crop can withstand without visible harm a minimum depth of 0.25 m. With a rise of groundwater table to 0.5 m for long periods the yield decrease is 20 to 40 percent.

The crop is moderately tolerant to soil salinity but the ECe should not exceed 4 mmhos/cm in the upper soil layer during germination. Yield decrease due to salinity is 0% at ECe 6.0, 10/ at 7.4, 25% at 9. 5, 50% at 13 and 100% at ECe 20 mmhos/cm.

With pre-irrigation or sufficient rain to wet the upper soil layer, seeds are drilled 2 to 4 cm deep. as against 5 to 8 cm in dry soils, so that light showers will not cause the seeds to germinate. Under favourable water supply including irrigation and adequate fertilization row spacing is 0.12 to 0.15 m (450 to 700000 plants/ha) but increases to 0.25 m or more under poor rainfall conditions (less than 200000 plants/ha). Sowing rates under irrigation are 100 to 120 kg/ha (drilled) to 110 to 140 kg/ha (broadcast). Wheat is often grown in rotation and legumes, sunflower and maize are considered as suitable rotation crops.

The graph below depicts the crop stages of wheat, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length, daysWheatWinter Wheat2015404020201301602530306050601140756065406060704075304020403030302513515013020016018024O335Mar/AprJulyAprilNovDecDecNovOct.35 - 45�LEast AfricaCalf.Desert,USACalf.,USAMediterraneanIdaho, USADepletionCoefficient, pSpring WheatWinter

Wheat0.50.6>>>>0.50.60.80.90.550.55Root Depth, m�Spring WheatWinter Wheat0.30.3>>>>>>>>1.21.4--�Crop Coefficient,�KcSpring Wheat�Winter Wheat with- frozen soils�-non-frozen soils0.30.40.7>>>>>>1.151.151.150.25-0.4020.25-0.4020.25-0.402-��Yield Response�Factor, KySpring WheatWinter Wheat0.20.20.650.60.550.5--1.051.151These periods of winter wheat with lengthen in frozen climates according days having zero growth potential and wheat dormancy. Under general conditions and in the absence of local data , fall planting of winter wheat can be presumed to occur in northern temperate climates when the 10-day running average of mean daily air temperature decreases to 17�C or Decenmber 1, whichever comes first. Planting of spring wheat can be presumed to occur when the 10-day running average of mean daily air temperature increases to 5�C. Spring planting of maize-grain can be pressure.

2The higher value is for hand-harvested crops.For high yields water requirements (ETm) are 450 to 650 mm depending on climate and length of growing period. The crop coefficient (kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is: during the initial stage 0.3-0.4 (15 to 20 days), the development stage 0.7-0.8 (25 to 30 days), the mid-season stage 1.05-1.2 (50 to 65 days), the late-season stage 0.65-0.7 (30 to 40 days) and at harvest 0.2-0.25.Following figure shows growth periods of winter and spring wheat (Large, 1954)

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of spring wheat are shown in the figure below.

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of winter Wheat are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Grain yield and grain straw ratio are-related to the duration and intensity of water deficit but the relations vary depending on the growth period during which the deficits occur. There is, however, some variation in variety as to the magnitude of the resulting yield decrease.

The relationships indicate that sensitivity to water deficit is somewhat higher in spring that in winter wheat, and this difference is thought to be the result of 'conditioning' of winter wheat which enables it to adjust its growth better in relation to water deficit.

For most varieties and particularly for the high producing varieties, early irrigation or heavy pre-and early season rain can produce good yields particularly when soils are deep and have a good water holding capacity and with an adequate amount of stored soil water, significant water deficits may occur only in the yield formation period (3). Only with irrigation or rain in the early growth periods (0 and 1a) plant and head number per m2 are considered higher compared to no rain or irrigation. In the latter situation the time to heading is also usually shortened.

Slight water deficits in the vegetative period (1) may have little effect on crop development or may even somewhat hasten maturation. The flowering period (2) is most sensitive to water deficit. Pollen formation and fertilization can be seriously affected under heavy water stress and during the time of head development and flowering water shortage will reduce the number of heads per plant, head length and number of grains per head. At the time of flowering root growth may be very much reduced and may even cease and considerable damage can be caused in this period. The loss in yield due to water deficits during the flowering period (2) cannot be recovered by providing adequate water supply during the later growth periods.

Water deficit during the yield formation period (3) results in reduced grain weight and hot, dry and strong wind in combination with a water deficit during this period causes shrivelling of grain. During the ripening period (4) a drying-off period is often induced by discontinuing irrigations and water deficit during this period only has a slight effect on yield.

In summary, provided there is adequate water during the establishment period (0) the critical periods for water deficit are:Wheat has the ability to form additional tillers when heavy water stress during the late vegetative period (1c) is followed by heavy water application. Yields may be improved through the formation of additional heads but harvest is delayed and losses from other causes such as lodging and non-uniform ripening are often increased.Following figure shows critical periods for water deficit of wheat

Wheat has a primary system and later it develops a fibrous root system. The latter roots are formed from the nodes which are at or near the ground surface. Depth and density of rooting are affected by water, nutrients and oxygen in the soil. In deep soils, the active rooting depth for spring wheat is 0.9 m with a maximum of 1.2 to 1.5 m and a spread of 0.15 to 0.25 m in all directions. For winter wheat, active rooting depth is up to 1.2 m with maximum of 1.5 to over 2 m and a similar spread. The top root ratio increases with crop development and is about 2 during the vegetative period (1), about 4 before heading, and about 10 to 11 during the yield formation (3) and ripening (4) period. In winter wheat the primary root system is developed in the autumn and full rooting depth in the spring is reached earlier than in spring wheat which requires 50 to 75 days after emergence to reach full depth.

Water uptake and extraction patterns are related to root density. In general 50 to 60 percent of the total water uptake occurs from the first 0.3 m, 20 to 25 percent from the second 0.3 m, 10 to 15 percent from the third 0.3 m and less than 10 percent from the fourth 0.3 m soil depth. Normally 100 percent of the water uptake occurs over the first 1.0 to 1.5m (D = 1.0-1.5m). Under conditions when maximum evapotranspiration is about 5 to 6 mm/day water uptake of the crop is little affected at soil water depletion of less than 50 percent of the total available soil water (p = 0.5). Moderate water stress to the crop occurs at depletion levels of 70 to 80 percent and severe stress occurs at levels exceeding 80 percent.Taking into account ETm, for non-stress conditions about 50 to 60 percent of available soil water can be utilized by the crop before the next irrigation, with somewhat higher depletion levels during the.ripening period (4). There is a distinct advantage for both winter and spring wheat in having the entire root zone filled to field capacity prior to or soon after sowing to attain optimum root development. Over watering during the vegetative period (1) produces luxurious growth that can cause lodging, which may also occur after a too heavy irrigation in the late yield formation period (late 3), particularly with sprinkler irrigation.

Where rainfall is low and irrigation water supply is limited, in addition to preirrigation, applications should be scheduled to avoid water deficits during the flowering period (2) and at about 50 to 70 days after sowing of spring wheat. Irrigation and rainfall during the late yield formation period (late 3) show little effect on yields when sufficient soil water in the root zone is carried over from the previous period to see the crop into the ripening period.To irrigate a large area most efficiently with limited water supply: one heavy autumn irrigation to wet the full root zone during September-November, one spring irrigation and one irrigation in the flowering period (2).

High yield with one full irrigation and one to four spring irrigations with soil water depletion-in the first 1 m soil depth not exceeding 70 percent of the total available water.

One irrigation during the establishment period (0) but still beneficial when applied as late as the flowering period.(2). With two irrigations, highest yields when applied during early vegetative (la) and flowering periods. With three irrigations the additional application is given at the late vegetative period (lc) but the effect on yield between two and three spring irrigations may be small.

Sowing in dry soil with application of 150 min after sowing; in the case of substantial rain, irrigation should bring the upper 0.6 m to field capacity. The second irrigation is applied when water depletion in the upper 1 m has reached 100 to 120 mm. In average years no further irrigation is required until heading. If at flowering (heading) soil water depletion is less than 30 mm, irrigation can be delayed until early yield formation period (early 3) when the first 0.6 m is brought to field capacity. If at heading soil water depletion is greater than 50 mm irrigation should be applied at that time with no further irrigation afterwards.

During early growth adequate water should be available in the soil profile and one application of 150 mm is recommended. Winter rains of 250 mm are usually adequate to bring the crop to maturity. At flowering 150 mm of available soil water should be stored in the root zone; when smaller, an additional irrigation is required.

In addition to pre-irrigation, one irrigation during early vegetative period (la); two irrigations - one during early vegetative period (1a) and one just prior to head emergence through flowering period (2); three irrigations - during early vegetative period (1a), just prior to head development through flowering period (2) and early yield formation period (early 3); four irrigations - during early vegetative (1a), late vegetative (1c), flowering (2) and early yield formation (early 3) periods.Under irrigation a good commercial grain yield is 6 to 9 ton/ha (10 to 13 percent moisture). The water utilization efficiency for harvested yield (Ey) for grain varies then between 0.8 and 1.6 kg/m3. ��� � This section presents information on water relations and water management of cotton and provides links to other sources of information.Cotton (Gossypium hirsutum) is grown for fibre and seed. Present world production is about 21 million tons lint and 59.7 million tons seed cotton from about 33.98 million ha. (FAOSTAT, 2001). The origin of cotton is still uncertain. The development of the crop is sensitive to temperature. Cool nights and low daytime temperatures result in vegetative growth with few fruiting branches. The crop is very sensitive to frost and a minimum of 200 frost-free days is required. The length of the total growing period is about 150 to 180 days. Depending on temperature and variety, 50 to 85 days are required from planting to first bud formation, 25 to 30 days for flower formation and 50 to 60 days from flower opening to mature boll. No clear distinction can be made in crop growth periods since vegetative growth is continued during flowering and boll formation and flowering is continued during boll formation.

Cotton is a short-day plant but day-neutral varieties exist. However, the effect of daylength on flowering is influenced by temperature. Germination is optimum at temperatures of 18 to 30�C, with minimum of 14�C and maximum of 40�C. Delayed germination exposes seeds to fungus infections in the soil. For early vegetative growth, temperature must exceed 20�C with 30�C as desirable. For proper bud formation and flowering, daytime temperature should be higher than 20�C and night temperature higher than 12�C, but should not exceed 40 and 27�C respectively. Temperatures between 27 and 32�C are optimum for boll development and maturation but above 38�C yields are reduced.

Strong and/or cold winds seriously affect the delicate young seedlings and at maturity will blow away fibre from opened bolls and cause soiling of the fibre with dust.

Cotton is extensively grown under rainfed conditions. Although the crop is relatively resistant to short periods of waterlogging, heavy rainfall, however, can cause lodging. Continuous rain during flowering and boll opening will impair pollination and reduce fibre quality. Heavy rainfall during flowering causes flower buds and young bolls to fall.

Cotton is grown on a wide range of soils but medium and heavy textured, deep soils with good water holding characteristics are preferred. Acid or dense subsoils limit root penetration. The pH range is 5.5 to 8 with 7 to 8 regarded as optimum. The fertilizer requirements of cotton under irrigation are 100 to 180 kg/ha N, 20 to 60 kg/ha P and 50 to 80 kg/ha K. Two-thirds of the nutrients are taken up during the first 60 days of the growing period. Nitrogen should be readily available at the start of -the growing season; normally two applications are given with one after sowing and the other prior to flowering. Phosphate is applied before sowing. Plant spacing normally varies between 50/100 x 30/50 cm.

The crop is tolerant to soil salinity. Yield decreases at different ECe values are: 0% at ECe 7.7 mmhos/cm; 10% at 9.6, 25% at 13, 50% at 17 and 100�/ at ECe 27 mmhos / cm .

The graph below depicts the crop stages of cotto n, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length, days304530305090505060456055554555451952251951 80Mar-MayMarSepAprEgypt; Pakistan; Calif.Calif. Desert, USAYemenTexasDepletion Coefficient, p0.6>>0.60.90.65�Root Depth, m0.3>>>>1.4-�Crop Coefficient,�Kc0.35>>1.15-1.20.7-0.50-��Yield Response Factor, Ky0.20.5-0.250.85�Depending on climate and length of the total growing period, cotton needs some 700 to 1300 mm to meet its water requirements (ETm). In the early vegetative period, crop water requirements are low, or some 10 percent of total. They are high during the flowering period when leaf area is at its maximum, or some 50 to 60 percent of total. Later in the growing period the requirements decline. In relation to reference evapotranspiration (ETo) the crop coefficient (kc) for the different development stages is: for the initial stage 0.4-0.5 (20 to 30 days), the development stage 0.7-0.8 (40 to 50 days), the mid-season stage 1.05-1.25 (50 to 60 days), the late-season stage 0.8-0.9 (40 to 55 days), and at harvest 0.65-0. 7.Following figure shows growth periods of cotton (after P.T. Walker)

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of cotton are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

The crop growth periods for cotton are shown in Figure 14. The relationships between relative yield decrease and relative evapotranspiration deficit are shown in Figure 15. For calculation examples see p. 40 and Chapter V1.

Adequate water supply is needed for vigorous growth, good budding and fruiting and for the formation of healthy bolls. Excess water early in the growing period will restrict root and crop development. Cotton requires adequate water supply particularly just prior and during bud formation (2a). Continued water supply during flower opening (2b) and yield formation (3) periods results in prolonged and excessive growth and yield. Abrupt changes in water supply will adversely affect growth and cause flower and boll shedding. Severe water deficits during flowering may fully halt growth, but with subsequent water supply crop growth recovers and flower formation is resumed.

When the growing season is short such conditions lead to smaller yield. Water stress on cotton can be observed by discolouring of the stem and appearance of a bluish-green colour on the leaves.

Water supply for high production must be adjusted to the specific requirements of each growth period (see Scheduling). Optimum use of available water supply can be made by fully wetting the entire root zone up to 1.80 m at sowing and with subsequent wetting of the upper part (0. 50. to 1 m) of, the root zone only. Root activity may be increased' and full utilization of the availble soil water over the entire root zone is made with little or no soil water left at the end of the growing season. Other savings can be made by utilizing the available water in the entire root depth by timely discon-tinuing irrigation applications at the end of the total growing period. Also savings can be achieved by withholding supply during the flowering period (2) until some 70 percent of the total available soil water has been taken up by the crop. A combination of the above practices may save up to 20 percent water without greatly impairing yields.

At sowing, adequate soil water should be available for germination and establishment (0). During the vegetative period (1), soil water content over the root depth of some 0.75 m should not fall below 50 percent depletion; greater depletion of available soil water (up to 75 percent) will restrict vegetative growth but when followed by ample supply, vegetative growth will be somewhat excessive, which may cause late flowering, boll shedding and reduced yield when the growing season is short. At flowering (2), supply will need to be scheduled to control vegetative growth in relation -to productive growth. Water deficits from onset of flowering to peak flowering may cause a more negative effect on yield as compared to when occurring after peak flowering. With severe water deficits during late flowering and early boll formation, boll shedding can be excessive. Moderate water deficit occurring during flowering (2) but high enough to restrict vegetative growth, will lead to good boll-set and higher yields, despite a reduction in number of flowers.

Adequate water supply should be available during the yield formation period (3). Depending on water holding capacity of the soil, development of the root system and evaporative demand, the water supply during the yield formation period (3) should be discontinued at a certain time before the ripening period (4). Excessive water supply during the yield formation period (3) may cause delay in boll opening and greater susceptibility to lodging and boll-rot. Under conditions of a long and warm growing season, an irrigation after the first harvest is sometimes practised to obtain a second yield. When water supply is limited, a higher total production is obtained by extending the area and partially meeting crop water requirements rather than by meeting full crop water requirements over a limited area.From emergence to early flowering, the tap root may extend in deep soils to a depth of 1.8 m. During the flowering period, additional root development occurs in the upper part of the root zone. Frequent, light irrigation application during early growth periods tends to cause shallow root systems. As a rule, some 70 to 80 percent of the total water uptake by the crop occurs over the first 0.9 m depth, where more than 90 percent of the total root weight is found. Normally when the crop is fully grown, 100 percent of the water is extracted from the first 1.0 to 1.7 m soil depth (D = 1.0- 1.7 m). When water supply is terminated, water uptake will increasingly occur from lower soil depths but may not be sufficient during peak water requirement periods to maintain crop evapotranspiration and crop growth. Under conditions when ETm is 5 to 6 mm/day water uptake starts to be reduced when soil water depletion exceeds 65 percent (p = 0.65).To enhance root development, adequate water should be available in the soil at the time of sowing and pre-irrigation is required when stored soil water from pre-season rainfall is not available. In the vegetative period (1) irrigation may be scheduled when some 60 percent of the available soil water over the first 0.75 m has been taken up by the crop. During flowering (2) depletion of some 70 percent of available soil water will in general check vegetative growth without impairing yields; delayed irrigation during this period may cause considerable flower and bud shedding. During yield formation (boll filling) (3) and ripening (4), the soil water depletion may increase from 60 percent to higher values as the season progresses and depending on climate and depth of stored soil water, irrigation can be terminated 4 to 5 weeks before final picking. When grown under conditions of high groundwater tables, even for short duration, and when soils are wet for long periods, the yield decrease may be up to 50 percent, not withstanding unrestricted water use. This may be due to inadequate soil aeration. The same phenomenon has been noticed under very frequent irrigation application.Cotton is grown under a great variety of irrigation systems of which furrow irrigation is the most common surface system. In regions where the demand for water is great and water resources are small, sprinkler and drip irrigation methods become more and more accepted to economize on water applied and restrict return flow of low quality. In the Near East region, cotton is also grown under controlled flood or spate irrigation, where with little or no rain a one-time pre-sowing irrigation of 0. 5 to 1 m depth stores sufficient water in the root zone to allow the crop to reach maturity. Under such treatments soils must be deep and have a high water holding capacity. With growing season from August to March with ETm = 700 to 750 mm and ETa = about 450 mm, farmers' yields are about 800 kg/ha, with a maximum of about 1 700 kg/ha seed cotton.A good yield of a 160 to 180 day cotton crop under irrigation is 4 to 5 ton/ha seed cotton of which 35 percent is lint. Water utilization efficiency for harvested yield (Ey) for seed cotton containing about 10 percent moisture is 0.4 to 0.6 kg/m3. Boll and fibre properties such as lint to seed ratio, and length, strength and fineness of lint, are primarily determined by the variety and to a lesser extent by irrigation and fertilizer practices. In general, the boll size, and the seed and lint index (weight per 100 seeds) increases under adequate water supply. However, the lint percentage (the ratio lint to seed) tends to decrease. Low soil water depletion levels during yield formation (3) tend to result in longer and finer fibre of decreased strength. The direct effect of water deficits on fibre properties, however, appears to be small because of the shedding of bolls which would have produced inferior fibre when allowed to mature.

Normally cotton seed contains 35 percent oil and 35 percent protein. Under irrigation there is an indication that severe water deficits substantially reduce the oil percentage in the seed, and more fibrous material with 20 percent lower oil and protein content is produced compared to an adequately irrigated crop. ��� � This section presents information on water relations and water management of alfalfa and provides links to other sources of information.Alfalfa (Medicago sativa) is believed to have originated in the Mediterranean region. It is grown as a forage crop, either for fresh produce or for hay. The crop is grown under a wide range of climates where average daily temperature during the growing period is above 5�C. The optimum temperature for growth is about 25�C and growth decreases sharply when temperatures are above 30�C and below 10�C. In warm climates the production is higher under dry as compared to humid conditions. Alfalfa can be used as an important break crop in the rotation and most crops can follow alfalfa with the exception of certain root crops such as sugarbeet, because of the high amount of root residue left in the soil.

Alfalfa is a perennial crop and produces its highest yields during the second year of growth. In climates with mild winters, alfalfa is grown for 3 to 4 years continuously, but in continental climates with cold winters it is grown for 6 to 9 years, with a dormant period in winter. The crop is also grown as a short season annual crop. Following seeding, the crop takes about 3 months to establish. Number of cuts varies with climate and ranges between 2 and 12 per growing season. Also, yield per cut for a given location varies over the year due to climatic differences.

Water use by the crop in relation to its production is high when compared to other forage crops such as forage maize, and when economic conditions permit alfalfa is replaced by maize as a forage crop.

Alfalfa is successfully grown on a wide variety of soils, with deep, medium textured and well-drained soils being preferred. Fertilizer requirements vary with production level and are 55 to 65 kg/ha P and 75 to 100 kg/ha K. (Fertilizer requirements (kg nutrient/ha) of high-producing varieties under irrigation; accurate amounts are to be obtained from local research results or to be determined by experiments, soil testing and plant analysis and evaluation of economic conditions. Conversion: 1 kg P = 2.4 kg P2O51 kg K = 1.2 kg K2O.) Alfalfa is capable of fixing atmospheric nitrogen which meets its requirements for high yields. However, a starter of approximately 40 kg N is beneficial for good, early growth.

The crop is moderately sensitive to soil salinity. Yield decrease related to electrical conductivity (ECe of extraction saturated paste in mmhos/cm) is: 0% at ECe 2.0 mmhos/cm, 10% at 3.4, 25% at 5.4, 50% at 8.8, and 100% at ECe 15.5 mmhos/cm.

The graph below depicts the crop stages of alfalfa, and the table summarises the main crop coefficients used for water management.

Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days Alfalfa,�total season11030var.var.var.Stage length,�days - Alfalfa 1st�cutting cycle10102030202510106075JanApr (last -4�C)Calif., USAIdaho, USAStage length,�days - Alfalfa�other cutting�cycles5510201010510 3045MarJuneCalif., USAIdaho, USADepletion�Coefficient, p:-for hay-for seed--------0.550.60��Root Depth, m-----Crop Coefficient, Kc: Afalfa Hay-averaged cutting effects-individual cutting periods-for seed0.400.4020.40>>>>>>0.9511.2021.150.901.1520.50---Yield Response Factor, Ky----1.1�1�This Kcmid cooefficient for hay crops is an overall average Kcmid cooefficient that averages Kc for both before and following cuttings. It is applied to the period following the first development period until the beginning of the last late season period of the grwoing season.

These Kc coeffecients of the for hay crops represent immediately following cutting; at full cover; and immediately before cutting respectively. The growing season is described as a series of individual cutting periods.Crop water requirements (ETm) are between 800 and 1600 mm/growing period depending on climate and length of growing period. The variation in water requirements in each cutting interval for alfalfa is similar to that during the total growing period from sowing to harvest for other crops. The kc value is about 0.4 just after cutting, increasing to 1.05 to l.2 just prior to the next cutting with a mean value of 0.85 to 1.05. For seed production, the kc value is equal to 1.05 to 1.2 during full cover until the middle of flowering, after which the kc value is reduced sharply.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration for alfalfa are shown in the figure below.

To stimulate root growth, the young stand should be irrigated frequently because root development is adversely affected by dryness. During each cutting interval the amount of total green matter produced increases to a maximum at the start of flowering when the quality for hay production is also at its best. To enhance growth, irrigation is normally applied just after cutting. When irrigation is applied just before cutting the top soil may still be wet at the time of cutting, hampering cutting and causing the cut material to mould more easily.

Excess irrigation may cause reduced soil aeration which is particularly harmful to the crop. During winter, when the crop i s dormant or growing very slowly, the crop will tolerate short periods of flooding without causing much damage to the later growth of the crop.

The relationship between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit (1 - ETa/ETm) is given in Figure 6. Within a certain range of relative evapotranspiration deficit (0 to 0.4), the yield response factor (ky) for both fresh and dry yield is smaller than one. This implies that water utilization efficiency (Ey) (kg of produce/m3 of water) increases in this range of relative water deficit. Under conditions of limited water supply, overall production is increased by extending the area under irrigation rather than by meeting full crop water requirements over a limited area. Also, the effect of a reduced water supply on yield of alfalfa is less pronounced than that of many other crops that have ky values greater than one during the period of water shortage. Where cropping of several crops is involved, the irrigation supply to alfalfa may be reduced in favour of more sensitive crops.

To reduce peak demands for water during the hot summer months, a dormancy period during these months is sometimes practised in North Africa. Water savings are utilized during spring and autumn when climatic conditions allow high yields with relatively lower water requirements. Where the crop is grown for seed, effective water savings may be made by timing the seed production during the period when normal water demands of a forage crop would be high.

The 'drought tolerance' of alfalfa, sometimes claimed during periods of low water requirements, appears to be due to its extensive rooting system which enables the crop to draw water from a large soil volume.Cuts are normally taken at the start of flowering when the vegetative growth slows down. Temperature has a pronounced effect on cutting interval and cutting interval at different mean daily temperatures is:Tmean, �C101520253035Interval, days(100)5035252018When water and other growth factors are not limiting, a first indication of the time and number of cuts for a given location can be obtained from the summation of daily mean temperature (T) above 5�C and the time of cut is found when the sum T - 5 = 500 to 550 degree days.Following figure shows an example of cutting intervals over the growing period.�Alfalfa has a deep rooting system extending up to 3 m in deep soils. The maximum root depth is reached after the first year. The crop can draw water from great soil depth and little response to irrigation has been shown with groundwater tables at 2 m or higher. Normally, when the crop is fully grown, 100 percent of the water is extracted from the first 1 to 2 m soil depth (D = 1-2 m). When maximum evapotranspiration (ETm) is 5 to 6 mm/day, about 50 percent of the total available soil water can be depleted before the uptake of water from the soil affects crop evapotranspiration (or p = 0. 5). After cutting full cover is reached in 12 to 20 days depending on temperature, and peak ETm is reached soon after.To obtain maximum yields under conditions where water supply is not limited, an adequate supply to; meet crop water requirements during the whole cutting, interval is advisable. Irrigation practice for hay production varies with an application just after cutting to enhance rapid growth, or at the time when the crop is reaching full cover and water requirements are near maximum. Irrigation immediately following removal of the cut crop is often practised on land difficult to irrigate. Late application may result in soil remaining wet, thus delaying the drying of hay on the ground. For conditions free from water stress and depending on the level of maximum evapotranspiration (ETm), a soil water depletion level of about 50 percent of the total available soil water (p = 0.5) is permissible.Surface irrigation is commonly used in alfalfa production. The most common method is border irrigation. Contour irrigation and wild flooding are sometimes practised. Where water is scarce or the soil permeability is high, water is supplied by overhead sprinkling.Crop yield varies with climate and length of total growing period. Good yields after the first year are in the range of 2 to 2. 5 tons/ha per cut (hay with 10 to 15 per cent moisture) of about 25 to 30 day cutting interval. For example, Hofuf, Saudi Arabia, 28 ton/ha of hay over 310 days involving 12 cuts; Davis, California, under experimental conditions, 22 ton/ha of hay over 200 day growing period involving 7 cuts. The water utilization efficiency for harvested yield (Ey) of hay with 10 to 15 percent moisture is 1. 5 to 2.0 kg/ m3after the first year. The moisture content of fresh green matter is about 80 percent. From 18 to 20 percent of the dry weight is protein. ��� � This section presents information on water relations and water management of citrus and provides links to other sources of information.Citrus species are perennial in growth habit. The most commonly cultivated species are�Citrus aurantifolia�(lime),�Citrus aurantium�(sour or Seville orange), Citrus grandis�(pummelo, shaddock),�Citrus limon�(lemon),�Citrus medica�(citron),�Citrus paradisi�(grapefruit),�Citrus reticulata�(mandarin, tangerine) and Citrus sinensis�(sweet orange). Present world production of citrus is about 98.7 million tons of fresh fruit, of which 62 percent is orange, 17 percent mandarin and tangerine, 5 percent citron, 11 percent is lime and lemon and 5 percent grapefruit. (FAOSTAT, 2001). The quantity of fresh fruit entering international trade is only exceeded by banana.

Citrus originates from the wet tropics in Southeast Asia, but large-scale commercial production is found in the subtropics under irrigation. In addition to fresh fruit and juice, citrus is grown for production of oil and citric acid.

Citrus trees normally start bearing fruit from the third year after planting, but economic yields are generally obtained from the fifth year onward. For flowering in spring a period of rest or reduced growth is needed. In the subtropics the low winter temperature induce:, this rest period, but in the absence of sufficient chilling, the rest period can be induced by water deficits.

Only a small percentage of the flowers produce mature fruits; during the flowering period fall of the weaker younger fruits occurs naturally and this is called 'June drop' in the northern or the 'December drop' in the southern hemisphere. Fruits take 7 to 14 months from flowering to maturity, corresponding to a harvest season from October /November to May/June in the northern hemisphere and from April/May to November/December in the southern hemisphere. Lemons, however, have a longer flowering period and are harvested throughout the year. For most cultivars, pollination is necessary for fruit development.

During ripening the amount of acid decreases while the sugar and aromatic substances increase. The fruit is of prime quality when sugar content is high. Picking takes place when the fruits are fully mature. Colour is not always an indication of fruit maturity. Degreening is conditioned by a period of cool weather. Green, mature fruits are obtained in the humid tropics, and with early or late season harvests in the subtropics. In the subtropics, fruits that have attained full colour, yellow or orange, in late autumn or early winter have been known to turn green again in spring, when not harvested. Fruits in the humid tropics tend to be large with thin, smooth rinds, a high juice content and lower total soluble solids and acid concentration.

Citrus is cultivated between 40�N and 40�S, up to 1800 m altitude in the tropics and up to 750 m altitude in the subtropics. For large-scale production geared toward export markets the crop is not suited to humid tropics because in addition to the difficulty of achieving the right fruit colour, humidity increases the incidence of pests and diseases. Only mandarins will tolerate humid conditions to a certain extent.

The optimum mean daily temperature for growth is 23 to 30�C. Growth is markedly reduced above 38�C and below 13�C. Active root growth occurs when soil temperatures are higher than 12� C. Most citrus species tolerate light frost for short periods only. Injury is caused by a temperature of -3�C occurring over several hours. Temperatures of -8�C cause branches to wither and -10�C generally kills the tree entirely. Flowers and young fruits are particularly sensitive to frost and are shed after very short periods of temperatures slightly below 0�C. Dormant trees are less susceptible to frost. Strong wind is harmful to citrus trees because flowers and young fruits fall easily; windbreaks are provided where necessary.

Citrus is grown on soils that are sufficiently aerated and deep to allow tap roots to penetrate to the desired depths (1-2 m). Light to medium textured soils, free from stagnant water and sticky impervious layers are preferred. Areas with a high water table should be avoided. Soil physical structure is of greater importance than the chemical properties, provided sufficient magnesium and minor elements such as zinc, copper and manganese are present in an available form. Soils with pH between 5 and 8 are preferred. The annual fertilizer requirements of citrus are 100 to 200 kg/ha N, 35 to 45 kg/ha P and 50 to 160 kg/ha K. Adequate fertility is important for both fruit quality and yield.

Citrus trees are sensitive to a high salt concentration in the soil. Yield decreases due to soil salinity are: 0% at ECe 1.7, 10% at 2.3, 25% at 3.3, 50% at 4.8, and 100% at ECe 8 mmhos/cm.

Propagation of citrus trees is done mostly by bud grafting, i. e. the insertion of buds of a desired variety on to a stock grown from seed of another variety. Normally citrus trees are transplanted. Planting distances vary according to soil conditions, the general topography, the variety and the type of tree to be planted, and are generally from 4 x 4 to 8 x 8. Planting may be square, rectangular, triangular or hexagonal. On steep slopes trees are planted in terraces or along contours. Tree density varies from 200 to 800 trees/ha. Young citrus orchards are often intercropped. In high rainfall areas permanent cover crops or broad-leaved weeds may be desirable, but in drier areas the soil is often kept bare. If an orchard is interplanted the companion crop should not strongly compete with the citrus trees for water and nutrients. A legume crop is often preferred.

The table below summarises the main crop coefficients used for water management.

Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days�609012095365JanMediterraneanDepletion Coefficient, p:----0.5Root Depth, m----1.2Crop Coefficient,Kc:�Citrus no ground cover70 % canopy50 % canopy20 % canopy0.70.650.5>>>>>>0.650.600.450.700.650.55---��Crop Coefficient,Kc:�Citrus no ground cover70 % canopy50 % canopy20 % canopy0.750.800.85>>>>>>0.700.800.850.700.800.85---Yield Response Factor, Ky----0.8-1.1��Citrus trees are evergreens and thus transpire throughout the year. Water requirements for high production vary with climate, ground cover, clean cultivation or no weed control, species and rootstock. The water requirements for grapefruit -are somewhat higher than for the other citrus species. In general total water requirements vary between 900 and 1200 mm per year.

The crop coefficients (kc) relating ETm citrus to the reference evapotranspiration (ETo) for the subtropics with winter rainfall are:JFMAMJJASONDLarge mature trees providing @ 70 % tree ground cover, clean cultivated.75.75.7.7.7.65.65.65.65.7.7.7No weed control.9.9.85.85.85.85.85.85.85.85.85.85The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of citrus are shown in the figure below.

As a perennial crop the response of citrus to water supply at a particular period of development will depend greatly on the level of water supply prior to that period during the same growing season and also the level of water supply during previous growing seasons.

In general, when water is insufficient, growth is retarded, leaves curl and drop, young fruits fall and fruits that mature are deficient in juice and inferior in quality. When the soil water depletion reaches permanent wilting point, tree growth is terminated and subsequently affects fruits and leaves, followed by twigs, branches and eventually the whole tree.

New vegetative growth in any year is influenced by residual effects of growth in previous seasons. The vegetative growth of young trees determines their final tree size and future fruit-bearing capacity. For mature trees, the growth vigour determines the replacement rate of fruit-bearing branches. Any effect of water deficit on root and leaf development may impair the number and size of fruits later in the season. Water deficits must be avoided when vegetative growth is most rapid. Prior to flowering and fruit set, however, too vigorous, luxurious growth may impair production of high quality fruit.

In citrus a rest period appears to be essential for flowering. The duration of the rest period determines the amount of flowers produced. The rest period, preferably of 2 months duration, can be induced either by low temperatures in winter (about. 10� C) in the subtropics and in the tropics by a period of water deficit (monthly rainfall or irrigation � 50 to 60 mm). The flower bud initiation occurs during this rest period when vegetative growth is minimum. Water deficits can have, however, some harmful effects for long-term crop production as compared to when dormancy is caused by a cold period. Once the rest period is ended, an adequate water supply is necessary because prolonged water deficits will not only delay flowering but also lead to over-production of flowers. This can result in lower yields during the next season and possibly in subsequent seasons to a biennial fruit-bearing cycle. For lemons, water deficits in summer are commonly used to start off-season flowering for year-round production.

The flowering period is very sensitive to water deficits. Water deficits directly reduce fruit set; also during this period nutrition, especially nitrogen, is essential and adequate water is necessary to make the nutrients available to the crop. Moreover, water deficit during fruit set reduces yield by causing a heavy June or December fruit drop.

Water deficits during June or December (early yield formation) can increase fruit shedding and reduce the rate of fruit growth. After June or December drop, water deficits can affect the final fruit size. The increase in fruit size from June or December to maturity is highly dependent on water uptake, and the rate of enlargement of immature fruit is an indication of the need for irrigation. However, soil water depletions resulting in moderate water deficits after July or January (yield formation and ripening) can be desirable because the content of soluble solids and acids in the fruit is increased; also, tree growth is reduced which facilitates picking. In addition, a slight reduction in fruit size is often commercially desirable. When soils are fine textured, moderate water deficits after early yield formation provide better soil aeration, and diseases such as root-rot (Phytophtora spp.) may be prevented.

A more severe water deficit during summer followed by irrigation may induce out-of-season flowering which generally results in a worthless second fruit production and causes a possible reduction of yield in the following main crop. Only lemon can produce all year round without harmful effects on tree growth or yield. For other citrus species, the production of a second crop is a fairly reliable indication that the tree has been short of water at some stage.

Because of the carry-over effects of water deficits on tree growth and later yields, the relation between yield decrease and relative evapotranspiration deficit only applies when year to year water deficits are of similar magnitude . Since data are largely obtained from subtropical climates with winter rainfall and where winter rainfall is sufficient to meet the crop water requirements in winter and early spring. The relationship in the figure presenting the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period applies to water deficits only during the period just prior to flowering to early harvest. However, variation in yield per tree is always likely to be considerable.Most citrus species develop a single tap root. The lateral roots ford a horizontal mat of feeding roots with weakly developed root hairs. Root development is largely dependent on the type of rootstock used and on the characteristics of the soil profile. Rooting depth varies between 1.20 and 2 m. In general, 60 percent of the roots are found in the first 0.5 rn, 30 percent in the second 0.5 m, and 10 percent below 1 m. Where water supply is adequate, normally 100 percent of the water is extracted from the first 1. 2 to 1. 6 m (D = 1. 2-1. 6 m) but under dry conditions the depth of water extracted below this depth increases. During prolonged periods of water deficit, soil water in a deep and well-drained soil may be utilized up to a soil depth of 2 or 3 m.Peak water requirements are reached between flowering and June or December drop. In this period frequent irrigation is necessary. When ETm is 5 to 6 mm/day, the fraction of available soil water (p) in this period equals about 0.4 but soil water depletion may be 60 to 70 percent from July or January to the end of autumn. During the latter period less frequent irrigation is advisable because during this period citrus is less sensitive to water deficits.

Irrigation scheduling requires great caution. Citrus trees demand good soil aeration and over-irrigation is highly detrimental, particularly to young trees. Too frequent and heavy irrigations may affect root development and yield and lead to leaching of nutrients. In climates where winters are too mild to induce a rest period, irrigation should be withheld for 2 to 3 months.The most common surface irrigation methods are furrow irrigation (several furrows between the tree rows), check irrigation (basins containing one or more trees) or flood irrigation (where citrus trees are planted on beds or ridges). Because of uneven water distribution and the difficulty of applying small amounts of water the importance of surface irrigation for citrus is decreasing.

Sprinkler irrigation may provide a more uniform distribution of water and the possibility of applying the exact depth of required water. With the drip or micro-jet systems, water savings may be obtained because water is applied only to the root zone, leaving the remaining part of the soil dry. Sprinkler irrigation is also frequently used for frost protection.Within an orchard yield varies greatly from tree to tree, while for a single tree yield varies from year to year. Sometimes a two-year fruit bearing cycle occurs.

Good yields of citrus are: orange - between 400 and 550 fruits per tree per year corresponding to 25 to 40 tons per ha per year; grapefruit - 300 to 400 fruits per tree per year and 40 to 60 tons per ha; lemons - 30 to 45 tons per ha per year; mandarin - 20 to 30 tons per ha per year. The water utilization efficiency for harvested yield (Ey) for citrus fruits is about 2 to 5 kg/m3�with a moisture content of the fruits of about 85 percent, except for lime which contains about 70 percent moisture. � � � � � � � � � � � � � � � � � � � � ��� � This section presents information on water relations and water management of grape and provides links to other sources of information.Grape is believed to originate from the Caspian and Caucasian regions. Most cultivated vines belong to the European type (Vitis vinefera), the American bunch type (V. labrusca�and its derivatives) or Muscadine type (V. rotundifolia). The total production of grapes is about 61.95 million tons from 7.3 million ha. (FAOSTAT, 2001)

Grape is grown between about 50�N and S, with suitable areas being small at these limits. The crop needs a long, warm to hot, dry summer and a cool winter. The subtropics with winter rain are most suited. Rain or cold and cloudy weather during flowering may adversely affect fruit setting whereas rain during ripening may lead to fruit rot. Where raisins are produced by sun-drying between the vine rows, at least one warm, sunny month without rain following harvest is essential.

In climates with a cool winter, the grape can survive temperatures down to -18�C, but once new growth begins, minor frost will kill the fruiting shoots. Rapid and succulent growth of shoots starts when mean daily temperatures reach l0�C. During flowering the rate of shoot growth declines and stops when the grapes are mature. The time from flowering to maturity can be expressed as the sum of mean daily temperature above 10�C or S(T - l0�C), which is about 900 degree-days for early varieties and 2000 for late varieties. Under cool to moderate warm weather, fruits ripen slowly and produce dry table wines of good quality. In warmer climates, the heat before and during ripening favours a high sugar content, which makes fruits better suited for port and sherry production. During and after harvest no new shoot growth should take place but leaves should be retained. In the autumn shoots, then also called canes, become woody and lose their leaves.

In the tropics (with less than 1 percent of the world production), the vine is an evergreen and can produce fresh fruits throughout the year. In general, two harvests of relatively poor quality and low yields are obtained annually with harvest dates controlled by adjusting the time of pruning.

Grapes are adapted to a wide range of soils, except when poorly drained or when salt content is high. In general, light soils are preferred. High production can be obtained under rainfed conditions, but without summer rain a deep soil with a high water holding capacity is required. Under irrigation, grape can be grown success-fully on shallow soils of 0.6 m depth or less.

On deep, fertile soil, the largest vines and high yields are produced. On soils of low fertility or limited depth, yields are usually lower, but fruit quality can be better. Fertilizer requirements are 100 to 160 kg/ha N, 40 to 60 kg/ha P and 160 to 230 kg/ha K. The greatest amount of nitrogen is needed during early spring growth and during the flowering period. During ripening, the nitrogen level must be low to prevent continuous vegetative growth.

Grape vines are moderately sensitive to soil salinity and yield decrease is 0% at ECe 1.5 mmhos/cm, 10% at 2.5, 25% at 4.1, 50% at 6.7 and 100% at 12 mmhos/cm.

Most grape varieties are propagated by cuttings, grown in a nursery for one year to produce roots. Where root louse is a problem, grape is grafted on resistant root-stocks. An important (and expensive) operation is the training, pruning and staking of the vines and thinning of clusters. In the tropics the time of pruning determines the time of fruiting. The plant spacing is also influenced by the.pruning and training practices and can vary between 1.5 x 3.5 and 4.5 x 5.5 m.

The graph below depicts the crop stages of grape, and the table summarises the main crop coefficients used for water management.

� �Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalGrapes-table or raisonStage length, days2020�2030405050601207590406060208024020518021О�AprilMarchMayApril�Low LatitudesCalif., USAHigh AltitudesMid Latitudes (wines)Depletion Coefficient, p----0.35�Root Depth, m1.5>>>>1.5�Crop Coefficient, Kc0.3>>0.850.45-�Yield Response Factor, Ky0.20.70.850.40.85�Grape-wineStage length, days2020�203040505012075904О� �6060�208024020518021О�AprilMarchMayApril��Low LatitudesCalif., USAHigh AltitudesMid Latitudes (wines)Depletion Coefficient, p----0.45�Root Depth, m1.5>>>>1.5�Crop Coefficient, Kc0.3>>0.70.45�Yield Response Factor, Ky0.20.70.850.40.85�The crop coefficient (kc) will vary with cultural practices. The kc value, relating the maximum water requirements (ETm) to the reference evapotranspiration (ETo), for clean cultivated conditions, infrequent irrigation and a dry soil surface most of the time is:JanFebMarAprMayJunJulAugSepOctNovDecMature grapevines grown in areas with killing frost; initial leaves early May, harvest mid-September; ground cover 40-50% at mid-season----.45-.5.65-.75.75-.9.8-.95.75-.9.65-.75--Mature grapevines in areas with light frost; initial leaves early April, harvest late August to early September; ground cover 30-35% at mid-season---.45-.5.55-.65.6-.75.6-.75.6-.75.6-.75.5-.65.35-.4-Mature grapevines grown in hot, dry areas and mild winter; initial leaves late February - early March, harvest late July; ground cover 30-35% at mid-season--.25.45.6-.65.7-.75.7-.75.65-.7.55.45.35-Total seasonal requirements vary between 500 and 1200 mm, depending mainly on climate and length of growing period.

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

Grape is a perennial crop and can adjust to a certain extent to limited water supply by developing a deep root system. When soil water even over great soil depth becomes limited and overnight recovery from wilting does not occur, growth will diminish and eventually stop. Subsequently leaf and shoot colour change to a dark greyish-green, the shoot tips become dry, the leaves curl, the tendrils abscise and eventually the leaves die and fall.

In the subtropics and temperate climates, flowerbud formation generally occurs during the late summer or autumn and the buds open during the next season. A slight deficiency of water, together with high sunshine and temperatures, is considered to be most favourable to flower bud formation. A dry summer and a relatively low yield appears to be more advantageous to flower bud formation than a wet summer and a heavy yield.

For good fruit production in the same year and the following years, good vegetative growth during the first part of the growing period (vegetative period, 1) is important.Water deficit should not occur during this period of rapid lateral shoot growth. The soil water content should preferably be at field capacity at the end of the winter, by winter rain or by irrigation, to ensure adequate water supply during the first months of the growing period. Especially shoot elongation is very sensitive to water deficits. Adequately irrigated vines have significantly more prunings than those grown under water deficit conditions. If water stress occurs abruptly, the growth is checked and wilting and dieback occur; if water stress develops gradually the vine growth is adjusted by lessened shoot growth, smaller production and earlier ripening. However, vegetative growth should be low during fruit formation and should stop toward harvest to ensure good ripening of the fruit and maturing of the wood.

Prior and during flowering (2), adequate water supply is necessary for flower development. Water deficits at this time retard flower development while severe water deficit reduces fruit set. Also the nutrition requirements of the grapevine are high during this period and the subsequent fruit enlargement period. Leaching of nutrients must be avoided in this period.

Yield formation (fruit enlargement, 3) depends on a steady, continuous water supply, but in this period the crop is less sensitive to water deficits than during the period of shoot growth (1). Water deficits during fruit enlargement reduce fruit size. Later irrigation does not result in undersized fruits becoming normal size. Water deficits prior to or just after veraison (start of ripening, fruits soften and change colour) affect fruit size more than deficits just before harvest.

Severe water deficit causes shrivelling of the fruits at all stages of yield formation (3) and ripening (4) and is first observed in the immature fruits on any cluster. The shrivelling usually disappears after rewatering. Complete desiccation is confined to the smaller fruits (less than about 4 mm in diameter). When the crop is subjected to severe water deficits after v6raison, maturity is delayed while the fruits may not even reach full maturity. A slight water deficit during the ripening period (4) may hasten maturity, while juice concentration is increased.

Water deficits throughout the growing season result in darker wine but may not affect the quality of the wine. Severe water deficit during yield formation (3) and ripening (4) results in the fruit having a dull colour. It also leads to sunburn but reduces the incidence of fruit rot. Severe deficits just after v6raison reduce the content of total soluble solids.

After the fruit is mature and especially after harvest, the vines become adjusted to a limited water supply. Normally no further growth occurs, but leaves are retained and canes ripen even though soil water content is low. In hot, dry regions, water deficit after harvest will cause the leaves to fall; when weather becomes cool in autumn, new leaves can be formed without becoming mature. This will lead to poor production in the next year. Water supply after harvest must therefore be sufficient to maintain the healthy foliage and to prevent premature leaffall. However, too much water after harvest causes new shoot growth, which has the same detrimental effects as new leaf growth. The relation between relative yield decrease and relative evapotranspiration deficit is given for conditions when soil water stress occurs mainly in the second part of the total growing period, and water supply during early vegetative growth (1) and the flowering period (2) is adequate (Fig. 16). To maximize total production if water supply is limited the cultivated area may be extended and crop water requirements partially met, rather than meeting full crop water requirements on a limited area.When root penetration is not obstructed, mature grapevines are deep rooted up to depths of 2 or 3 m, or more. In deep, coarse sand or gravelly soils, roots may be up to 4 to 8 m deep.The bulk of the roots are usually in the upper soil layer of 0.5 to 1.5 rn. Normally 100 percent of the water is extracted from the first 1 to 2 m soil depth (D = 1-2 m). During vegetative growth (1), flowering (2) and the early part of yield formation (early 3) maximum evapotranspiration will be affected at a soil water depletion (p) of about 0.35 to 0.45, under conditions when ETm is 5 to 6 mm/day. Later in the growing period the soil water can be depleted to a higher level, while toward and after harvest time a high soil water depletion is required.When winter rainfall is insufficient to fill the full root zone to field capacity, irrigation should be applied before vegetative growth starts. Until the beginning of the veraison water must be applied when 35 to 45 percent of the total available soil water is depleted. Whether irrigation is necessary after veraison depends on the total available water over the root depth in relation to ETm. In shallow and light soils, irrigation will be necessary until harvest, but be applied at higher soil water depletion levels (soil water potential between 1 and 5 bars).

In deep, fine textured soils irrigation should be discontinued in time to achieve the desired soil water depletion level toward harvest time. In warm, dry climates or when the grapes are harvested early, a light irrigation may, however, be required to prevent the soil from becoming too dry (water potential not exceeding 5 to 10 bars).

When sprinkler irrigation is practised, after veraison irrigation should not take place during humid periods in order to assure rapid drying of the leaves (8 to 12 hours), and to reduce foliar burn and the hazard of fruit rot.Furrow irrigation with 2 or 3 furrows between the rows is mostly used. Sprinkler irrigation becomes more common since it can also be used for spring frost protection where needed. Sprinkler is less advantageous when irrigation is also required during the ripening period because of the likely increase in bunch rot. In new vineyards and especially where irrigation water is scarce, drip irrigation is increasingly being introduced.Similarly to other perennial crops, yield per vine varies considerably from year to year and from plant to plant. The maximum yield level depends on the variety and growing environment. Good commercial yields in the subtropics are in the range of 15 to 20 kg grapes per vine or 15 to 30 (or more) tons/ha (80 to 85 percent moisture). Yields in the tropics are in the range of 5 to 10 ton/ha. The water utilization efficiency for harvested yield (Ey) for fresh fruits containing about 80 percent moisture is 2 to 4 kg/m3 when grape is grown in the subtropics. ��� � This section presents information on water relations and water management of pineapple and provides links to other sources of information.Pineapple (Ananas comosus) is a perennial crop grown for its fruits and used as a fresh and processed product. World production is about 13.7 million tons fresh fruit.(FAOSTAT, 2001).

The origin of the pineapple is still uncertain but the Parana-Paraguay Basin has been considered as a possible area. For good growth pineapple requires mean daily temperatures of 22 to 26�C with an optimum of 23 to 24�C. Mean daily maximum and minimum temperatures of 30 and 20�C respectively for the whole growing period are considered optimum. Temperatures below or above this range affect fruit quality or the acid and sugar content.

The crop is grown between 31�N and 34�S, primarily in regions with high relative humidity. A combination of optimum temperature and high humidity results in soft, large leaves and juicy fruits, low in acid content. Fruits ripening in periods with cool temperatures and low radiation levels, e.g. in winter or at high altitudes, are of inferior quality because of poor shape for canning. Requirements for canning are: a cylindrical shape, fruit eyes of a relatively shallow surface and a small fruit core in relation to the fruit.

Pineapple can grow on a wide range of soils but a sandy loam texture is preferred. Optimum soil pH is 4.5 to 6.5. The soil should have a low lime content. The crop is sensitive to waterlogging and therefore requires a well-drained soil with good aeration. For high production the fertilizer needs are 230 to 300 kg/ha N, 45 to 65 kg/ha P and 110 to 220 kg/ha K.

Pineapple is usually grown in double rows on raised beds. With a spacing of 0.6 x 0.3m in beds 0.75 to 0.90m apart, plant population is about 50000 per ha. Shading is sometimes used where temperatures are high and radiation intense to protect the crop from scorching. The crop is multiplied using slips, crowns and shoots or suckers, but in comparison with using suckers as planting material, the period from planting to harvest is about 20 percent longer when slips are used, and about 35 percent longer when crowns are used. Use of different planting material allows a manipulation of the crop growing period and particularly in selection of the time of harvest when climatic conditions are favourable for high quality fruits. Normally the plant crop is followed by one ratoon crop, but when climatic conditions are favourable, the crop will continue to bear fruits but quality rapidly declines after the first ratoon. However, in warm tropical climates, e.g. at low altitudes near the equator, no ratoon crop is possible because suckers do not develop. The period from planting to harvest of the plant crop is 1 to 2 years and of the ratoon crop 9 months to 1.5 years depending on planting material and climate.

The flower initiation in pineapple is induced by low temperature, water deficit or hormone spray; the latter results in a uniform fruiting and harvest period.

Plant crop, first ratoon and second ratoon (Collins, 1960)Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days�6012060030790FebruaryHawaii, USADepletion Coefficient, p:0.4>>0.40.4-Root Depth, m---0.5-Crop Coefficient,Kc1:with bare soilwith grass cover0.50.5>>>>0.30.50.30.5--��Yield Response Factor, Ky-----��Crop water requirements (ETm) for high production are very different from those of most other crops. Because there is a suspension of transpiration during the day, maximum evapotranspiration is low and varies between 700 and 1000 mm per year The crop coefficient (kc) relating reference evapotranspiration (ETo) to ETm is about 0.4 to 0.5 for the total growing period. The following figure shows growth periods of a 20-month pineapple (after E.A.C., 1977)

� Pineapple can survive long dry periods through its ability to retain water in the leaves which is used during these periods. Also due to its low water use, the plant can survive on a small depth of stored soil water. However, the crop is sensitive to water deficit, especially during the vegetative growth period, when the size and fruiting characteristics are determined. Water deficits retard growth, flowering and fruiting. Water supply during this period should meet full water requirements of the crop. Water deficit at flowering has a less serious effect and may even hasten fruiting and result in uniform ripening. An ample water supply at flowering will lead to vigorous stem growth and a large core which is disadvantageous when the fruit is used for canning.

Frequent irrigation or rain at the time of harvest may cause deterioration of the quality of the fruit and make the crop susceptible to the fungus causing heart rot. In addition, waterlogging affects fruit quality. Where water supply is limited, mulching is practised to reduce soil evaporation and soil temperature. Dew has been found to contribute to meeting the wafer requirements of the crop. The rooting system of pineapple is shallow and sparse. In deep soils, maximum root depth may extend up to 1m but roots are generally concentrated in the first 0.3 to 0.6 m, from which normally 100 percent of the water is extracted (D = 0.3-0.6 m). Under conditions when maximum evapotranspiration is 5 to 6 mm/day, water uptake starts to be reduced when about 50 percent of the available soil water has been depleted (p = 0.5).Adequate water supply is essential particularly during the vegetative period. The interval of application can be based on the prevailing rate of maximum evapotranspiration (ETm) and the fraction (p) of the total available soil water. Where rainfall is small and irrigation water supply is restricted, irrigation scheduling should be based on avoiding water deficits during the period of vegetative growth (1). Supply of water can be restricted during the period of ripening (4) whereas some water savings can be made by allowing higher depletion levels up to 75 percent during flowering (2). During the month prior to harvest irrigation is discontinued. The method of irrigation is mostly by sprinkler.The fruit contains about 80 to 85 percent water and 10 to 14 percent sugar. Irrigation has an effect on the sugar/acid ratio, particularly in the period prior to harvest when frequent high irrigation decreases the sugar content. The infestation by soil-borne fungus diseases is increased. Under commercial production, weight per fruit is about 1. 5 to 1.8 kg, and total yield between 75 and 90 ton/ha fresh fruit. The water utilization efficiency for harvested yield (Ey) for fresh fruit is about 5 to 10 kg/m3for the plant crop and 8 to 12 kg/m3for the first ratoon crop. ��� � This section presents information on water relations and water management of potato and provides links to other sources of information.Potato (Solanum tuberosum) originates in the Andes from the tropical areas of high altitude. The crop is grown throughout the world but is of particular importance in the temperate climates. Present world production is some 308 million tons fresh tubers from 19 million ha. (FAOSTAT, 2001).

Yields are affected by temperature and optimum mean daily temperatures are 18 to 20�C. In general a night temperature of below 15�C is required for tuber initiation. Optimum soil temperature for normal tuber growth is 15 to 18�C. Tuber growth is sharply inhibited when below 10�C and above 30�C. Potato varieties can be grouped into early (90 to 120 days), medium (120 to 150 days) and late varieties (150 to 180 days). Cool conditions at planting lead to slow emergence which may extend the growing period. Early varieties bred for temperate climates require a daylength of 15 to 17 hours, while the late varieties produce good yields under both long or short day conditions. For tropical climates, varieties which tolerate short days are required for local adaptation.

Potato is grown in a 3 or more year rotation with other crops such as maize, beans and alfalfa, to maintain soil productivity, to check weeds and to reduce crop loss from insect damage and diseases, particularly soil-borne disease. Potato requires a well-drained, well-aerated, porous soil with pH of 5 to 6. Fertilizer requirements are relatively high and for an irrigated crop they are 80 to 120 kg/ha N, 50 to 80 kg/ha P and 125 to 160 kg/ha K. The crop is grown on ridges or on flat soil. For rainfed production in dry conditions, flat planting tends to give higher yields due to soil water conservation. Under irrigation the crop is mainly grown on ridges. The sowing depth is generally 5 to 10 cm, while plant spacing is 0.75 x 0.3 m under irrigation and 1 x 0.5 m under rainfed conditions. Cultivation during the growing period must avoid damage to roots and tubers, and in temperate climates ridges are earthed up to avoid greening of tubers.

The crop is moderately sensitive to soil salinity with yield decrease at different levels of ECe: 0% at 1.7, 10% at 2.5, 25% at 3.8, 50% at 5.9 and 100�/ at ECe 10 mmhos/cm.

The graph below depicts the crop stages of potato, and the table summarises the main crop coefficients used for water management.Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days�25253045303030353035 30/45455070503030302025115/130130145165140Jan/NovMayAprilApr/MayDec(Semi)Arid ClimateContinental ClimateEuropeIdaho, USACalf. Desert, USADepletion�Coefficient, p:0.5>>0.60.90.5Root Depth, m0.3>>>>1.0-Crop Coefficient,Kc1:with bare soilwith grass cover0.5>>1.150.5-��Yield Response�Factor, Ky0.20.8-1.00.85��For high yields, the crop water requirements (ETm) for a 120 to 150 day crop are 500 to 700 mm, depending on climate. The relationship between maximum evapotranspiration (ETm) and reference evapotranspiration (ETo) is given by the crop coefficient (kc) which is: during the initial stage 0.4-0.5 (20 to 30 days), the development stage 0.7-0.8 (30 to 40 days), the mid-.season stage 1.05-1.2 (30 to 60 days), the late-season stage 0.85-0.95 (20 to 35 days), and at maturity 0.7-0.75.Following figure shows growth periods of potatos (after W. C. Sparks, 1972)

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Potato is relatively sensitive to soil water deficits. To optimize yields the total available soil water should not be depleted by more than 30 to 50 percent. Depletion of the total available soil water during the growing period of more than 50 percent results in lower yields. Water deficit during the period of stolonization and tuber initiation (1b) and yield formation (3) have the greatest adverse effect on yield, whereas ripening (4) and the early vegetative (la) periods are less sensitive. In general, water deficits in the middle to late part of the growing period thus tend to reduce yield more than in the early part. However, varieties vary in their sensitivity to water deficit. Some varieties respond better to irrigation in the earlier part of the yield formation period (3) while others show a better response in the latter part of that period. Yields of varieties with few tubers may be somewhat less sensitive to water deficit than those with many tubers.To maximize yield, the soil should be maintained at a relatively high moisture content. This, however, can have an adverse effect when frequent irrigation with relatively cold water may decrease the soil temperature below the optimum value of 15 to 18�C for tuber formation. Also, soil aeration problems can sometimes occur in wet, heavy soils.Since the potato is a relatively sensitive crop in terms of both yield and quality, under conditions of limited water supply the available supply should preferably be directed towards maximizing yield per ha rather than spreading the limited water over a larger area. Savings in water can be made mainly through improved timing and depth of irrigation application.Under evaporative conditions with ETm of 5 to 6 mm, the effect of soil water depletion up to 25 percent on yield is small (p = 0.25). Since potato has a shallow root system, normally 70 percent of the total water uptake occurs from the upper 0.3 m and 100 percent from the upper 0.4 to 0.6 m soil depth (D = 0.4-0.6 m). The uptake pattern will, however, also depend on the soil texture and structure.Where rainfall is small and irrigation water supply is restricted, irrigation scheduling should be based on avoiding water deficit during the period of stolonization and tuber initiation (1b) and yield formation (3) Supply of water can be restricted during the early vegetative (1a) and ripening (4) periods. Savings can also be attained by allowing higher soil water depletion toward the ripening period (4) so that all available stored water in the root zone is used by the crop. This practice may also hasten maturity. Correct timing of irrigation may save 1 to 3 irrigation applications including the last irrigation prior to harvest.Most common irrigation methods for potato are furrow and sprinkler. Yield response to frequent irrigation is considerable because the crop has a shallow root system and requires a low soil water depletion. For example, very high yields are obtained with the mechanized sprinkler systems where evapotranspiration losses 'are replenished each or every two days.Water supply and scheduling are important in terms of quality. Water deficit in the early part of the yield formation period (3) increases the occurrence of spindled tubers, which is more noticeable in cylindrical than in round tubered varieties. Water deficit during this period followed by irrigation may result in tuber cracking or tubers with black hearts. Dry matter content may increase slightly with limited water supply during the ripening period (4). Frequent irrigation does reduce occurrence of tuber malformation.

Good yields under irrigation of a crop of about 120 days in the temperate and subtropical climates are 25 to 35 ton/ha fresh tubers and in tropical climates yields are 15 to 25 ton/ha. The water utilization efficiency for harvested yield (Ey) for tubers containing 70 to 75 percent moisture is 4 to 7 kg/m3. ��� � This section presents information on water relations and water management of groundnut and provides links to other sources of information.Groundnut (Arachis hypogaea) originates from South America. Present annual world production of unshelled nuts is about 35.1 million tons from about 25.5 million ha.(FAOSTAT, 2001)

The crop is grown between 40�N and S latitudes. Its growing period is 90 to 115 days for the sequential, branched varieties and 120 to 140 days for the alternately branched varieties. The mean daily temperature for optimum growth is 22 to 28�C a reduction in yield occurs above 33�C and below 18�C. Germination is delayed at temperatures below 20�C. Groundnut is considered a day-neutral plant and daylength is not a critical factor influencing yield. For good yields, a rainfed crop requires about 500 to 700 mm of reliable rainfall over the total growing period.

The crop is best adapted to. well-drained, loose, friable medium textured soils. Heavy textures cause problems in lifting the crop at harvest. Also, the top soil should be loose to allow the pegs (on which the fruits are formed) to enter the soil easily.

Being a legume, groundnut can fix nitrogen from the air. However, a pre-planting nitrogen application of 10 to 20 kg/ha is often recommended to assure good crop establishment. Phosphorous requirements are 15 to 40 kg/ha; potassium requirements 25 to 40 kg/ha. A too high application of potassium can cause a decrease in yield. For proper kernel formation and pod-filling, 300 to 600 kg/ha of calcium i s required at the beginning of pod formation in the top soil where the fruits are formed. Limestone is used when soil acidity needs to be corrected and gypsum when only the Ca level needs to be increased. At pH lower than 6, liming may be necessary to avoid aluminium and manganese toxicity.

Groundut during ripening

The graph below depicts the crop stages of groundnut, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalStage length, days253535353545453535� �253525130140140� �Dry seasonMayMay/June� �West AfricaHigh LatitudesMediteranean�Depletion Coefficient, p0.45>>0.450.5�Root Depth, m0.25>>>>0.50-�Crop Coefficient, Kc0.4>>1.050.6-�Yield Response�Factor, Ky0.20.80.60.20.7Depending on climate, the water requirements range from 500 to 700 mm for the total growing period. As related to development stages, the kc value for the initial stage is 0.4-0.5 (15 to 35 days), the development stage 0.7-0.8 (30 to 45 days), the mid-season stage 0.95-1.1 (30 to 50 days), the late-season stage 0.7-0.8 (20 to 30 days), and at harvest 0.55-0.6.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Vegetative and reproductive growth show a definite response to water supply. However, excessive soil water is harmful because lack of oxygen in the soil limits the activity of the N-fixing bacteria; this is noted by an unhealthy growth pattern and yellowing of the leaves. Excessive soil water in heavy soils at harvest can cause the pods to be torn easily from the pegs with the pods remaining in the soil.

The flowering period (2) is most sensitive to water deficit, followed by the yield formation period (3). In general, water deficits during the vegetative period (1) cause delayed flowering and harvest, and reduced growth and yield. Water deficits during flowering (2) cause flower drop or impaired pollination, whereas water deficits during the yield formation period (3) give a reduced pod weight. The early part of the yield formation period (pod setting) is particularly sensitive to water deficit. In the case of limited water supply, water savings should be made during the periods other than flowering (2) and early yield formation (3). A higher total production is obtained by increasing the cultivated area and partially meeting crop water requirements rather than by meeting full crop water requirements over a limited area.

Following table presents the growth periods for groundnutCrop stageDays0Establishment10-201Vegetative25-352Flowering130-403Yield formation (including pod setting and pod filling)30-354ripening10-201�Flowering continues during part of teh yield formation but the pods from the late-formed flowers do not reach maturity.The crop has a well-developed tap root with many laterals which may extend to a depth of 1.S m. The major part of the root system is, however, found in the first 0.5 to 0.6 m soil layer. Full grown plants normally extract 100 percent of the water from the first 0.5 to 1.0 m of the soil (D = 0.5-1.0). Under an evapotranspiration rate of 5 to 6 mm/day, the rate of water uptake by the crop starts to reduce when some 50 percent of the total available soil water has been depleted (p = 0.5).Depending on the level of crop evapotranspiration and water holding capacity of the soil, intervals vary from 6 to 14 days up to 21 days for loam soils, with shorter intervals during flowering (2) when depletion of available soil water should not exceed 40 percent. In the case of supplemental irrigation, best results are obtained when water is applied during the flowering period (2).On light-textured soils, sprinkler irrigation offers advantages by light and frequent water application, sufficient to wet the first 0.6m of the soil. Furrow irrigation is frequently used on medium textured soils.Under rainfed conditions good average yields vary from 2 to 3 ton/ha unshelled nuts under a high level of management. Under irrigation and a high level 100 of management, yields can be 3.5 to 4.5 ton/ha unshelled nuts. The water utilization efficiency for the harvested yield (Ey) for unshelled, dried nuts with a moisture content of about 15 percent is 0.6 to 0.8 kg/m3. Groundnuts contain about 30 percent protein and are rich in vitamins B and C. The oil content for the Virginia bunch type (alternately branched), is between 38 and 47 percent; for the small seeded Spanish types (sequentially branched), 47 to 50 percent. Oil content is reduced considerably when water deficits occur during the yield formation period (3). ��� �
This section presents information on water relations and water management of olive and provides links to other sources of information.Olive (Olea europacal) probably originated from the Eastern Mediterranean region of the Middle East. Present production is about 16

million tons green and black table olives and 2.7 million tons oil. Of the total production, 95 percent is produced in the Mediterranean region with Spain and Italy being the main producing countries FAOSTAT, 2001) .

The crop is indigenous to the Mediterranean region with a mild, rainy winter and a hot, dry summer. A dormancy period of about two months with average temperatures lower than 10� C is conducive to flower bud differentiation. Some cultivars are adapted to areas with higher winter temperatures but reduced flowering is noted under these conditions. During the dormancy period, the tree tolerates short periods of frost of -6� C, but during the bearing period frost causes damage to the fruits which are then only suitable for oil production. High temperatures and dry winds cause poor fruit setting and excessive drop of young fruits with remaining fruits shrivelling on the tree. A long, sunny, warm summer results in a high oil content of the fruit. High humidity at f lowering causes flower drop and infestation of sooty mould.

The crop produces acceptable yields on poor soil as long as it is deep, well-aerated and free from waterlogging. Under waterlogged conditions damage through lack of oxygen and fungal diseases increases sharply. The fertilizer requirements are 200 to 250 kg/ha N, 55 to 70 kg/ha P and 160 to 210 kg/ha K. Nitrogen is applied prior to or during the flowering and fruit formation period.

The olive tree is moderately tolerant to soil salinity provided ECe does not exceed 8 mmhos/cm, but ECe of 4.5 mhos/cm or less is preferred.

Raised for two years in the nursery, the tree is transplanted early in the season with 15 to 20 trees/ha under poor rainfed conditions and up to 300 trees/ha under irrigated conditions. Tree density is also dependent on the method of pruning. Early pruning is not essential but is often practised to obtain strong stems. However, for older trees, pruning during winter is necessary for high yields. Intercropping with grain forage and vegetable crops is sometimes practised in young orchards but is discontinued after 15 to 20 years under rainfed and after 6 years under irrigation.

More fruits are set than can be supported by sufficient nutrient supply, and this tendency increases as the trees get older. Consequently, a small number of flowers produce fruits. Early flower drop can be attributed to inadequate pollination, nutrient deficiencies or water shortage. Late flower and fruit drop is caused mainly by olive moth and olive fly attacks and water shortage. On the other hand, abundant fruiting adversely affects growth of annual shoots and the next year crop and eventually leads to alternate fruit bearing. This tendency is greater in older trees but alternate bearing is less pronounced with good soil and climate, and adequate management practices. The economic life of a tree is 50 years under rainfed conditions but under favourable growing conditions it can be much longer. A profitable harvest is obtained after 6 years but under more extreme conditions, after 15 to 20 years.

The graph below depicts the crop stages of olive, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalStage length, days309060 �90270 ��- ���Depletion Coefficient, p----0.65�Root Depth, m----1.7�Crop Coefficient, Kc0.65>>0.700.70-�Yield Response�Factor, Ky0.2Olive trees are commonly grown without irrigation in areas with an annual rainfall of 400 to 600 mm but are even found in areas with about 200 mm rainfall. For high yields, 600 to 800 mm are required. The crop coefficient (kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is between 0.4 and 0.6.The annual growth cycle of the olive tree in the subtropics with winter rain, together with the timing of cultivation practices, is shown in the figure below.

In the subtropics with winter rain, adequate soil water is generally available until the later part of the summer. For high yields, adequate water is required from the start of the stone hardening onward until the end of yield formation (3). During the yield formation period (3) adequate water supply increases fruit size and the flesh/pit ratio but the ripening period (4) is prolonged and the colouring of the fruit is delayed. Table olives, with a high flesh/pit ratio, require more water during the yield formation period (3) than olives produced for oil. In subtropical climates with little winter rain, water supply is also needed prior to flowering (2). Water deficits during the flowering period (2) may result in increased flower and fruit drop. Where needed, irrigation prior to the, start of flowering is recommended because irrigation during the flowering period (2) may lead to leaching of the essential supply of soil nitrogen.

Yields are strongly affected by twig growth during spring and early summer (from April to June in the northern hemisphere) and adequate water should be avail-able during this time. This applies also to the winter period because water deficits in winter cause reduced twig growth and defoliation. Further, this also causes a large percentage of imperfect flowers during spring while retarding flowering.

Adequate water supply during the active growth periods tends to reduce alternate bearing cycles. Water deficits in the spring adversely affect lead development and active growth, causing a reduction in yield during the same year and possibly also the next. When the crop is grown fully under irrigation, application of water could be discontinued only during the period between start of f lowering and the beginning of stone hardening.

Excess water results in short twigs, dense foliage with short and narrow leaves and reduced yields.

Under conditions of limited water supply, overall production is increased by extending the area and partially meeting crop water requirements, rather than by meeting full crop water requirements over a limited area.After 3 to 4 years the tree forms a fascilar root system which continues to grow with age. In heavy textured and poorly aerated soils, roots are concentrated near the soil surface but are found at a greater depth in light textured soils. Lateral roots can be up to 12 m long. The tree thus explores a large volume of soil for nutrients and water. Generally, water uptake occurs over the first 1.2 to 1.7 m of soil depth (D = 1.2 to 1.7 m). Under conditions when maximum evapotranspiration (ETm) is 5 to 6 mm/day, the rate of soil water uptake by the crop starts to reduce when some 60 to 70 percent of the total available soil water has been depleted.With winter rain of about 500 mm, irrigation is applied during and after stone hardening. Under conditions of little winter rain, irrigation is applied during bud differentiation (early spring), prior to flowering (early summer) and during yield formation and particularly during stone hardening. Irrigation is also applied at (a) two to three weeks before flowering; (b) when the fruit reaches one third its full size; and (c) when the fruit reaches almost full size.

For oil production, irrigation supply must be discontinued early enough to give a dry period during ripening. This will have little effect on the oil content but will reduce the water content of the fruit.

Irrigation is applied by different surface methods, but when limited water is available, localized irrigation is preferred.The fruits of irrigated trees reach a high oil content later in the season than those of rainfed trees. Also, for irrigated trees the change of fruit colour from green to black is more gradual. Oil content as percentage of fresh fruit weight tends to be higher for rainfed than for irrigated trees but little difference is noted with oil content expressed as percentage of dry matter.

Time of picking depends on the use of the harvested product. Varieties with fruits of a high flesh/pit ratio and uniform shape are used for table olive production. In the northern hemisphere, green table olives are harvested from mid-September onward with end of harvest being determined when the fruit colour changes to green-yellow. Black table olives are harvested in December. Olives for oil are harvested from mid-December until March with oil content independent of the time of harvest.

Maximum oil content and weight are reached six to eight months after flowering. Olive fruits can be harvested long before they fall naturally.

Yields vary from year to year and from tree to tree. Good commercial yields under irrigation are 50 to 65 kg/tree of fruit with a possible maximum of 100 kg/tree of fruit. Oil content of the fresh fruit ranges from 20 to 25 percent. The water utilization efficiency for harvested yield (Ey) for fresh olives containing about 30 percent moisture is 1.5 to 2.0 kg/m3. ��� � This section presents information on water relations and water management of safflower and provides links to other sources of information.Safflower (Carthamus tinctorius) is only known in its cultivated form with centres of origin probably in the Near East. The estimated world production is about 0. 6 million tons of seed per year from about 0.85 million ha.(FAOSTAT, 2001). The flowers from the spiny cultivars are grown for oil, while some spineless cultivars are used for dye production.

Safflower is not suited to lowland, humid tropics. Large scale commercial cropping is practised in USA and USSR between 30� and 45�N and in Australia between 15� and 35�S. Emerging plants need cool temperatures for root growth and rosette development (mean daily temperature 15 to 20�C) and higher temperatures during stem growth, flowering and yield formation periods (20 to 30�C). There is no germination below 2�C. At 5�C germination takes 16 days and at 16�C, 4 days. The seedling is frost-resistant up to -7�C but after this stage frost below -2�C kills the plant. The crop seems to be sensitive to daylength but the effect is difficult to quantify. The length of the growing period for an autumn-planted crop varies from 200 to 230 days; when planted in spring, 120 to 160 days.

Safflower requires a fertile, fairly deep and well-drained soil. For irrigated production a medium-textured soil is preferable. Shallow soils seldom produce high yields. On suitable soils roots go down to 3.5m; dense subsoils retard root growth. The crop is well adapted to the presence of a water table at a depth of up to 1 m. Under irrigation, the fertilizer requirements are 60 to 110 kg/ha N, 15 to 30 kg/ha P and 25 to 40 kg/ha K. Though there is a rather wide tolerance to H, high yields are obtained on soils with a neutral reaction; when pH is lower than liming may be advisable.

The crop is moderately tolerant to salinity, ranking just below cotton. Yield decrease due to soil salinity is 0% at ECe 5.3, 10% at 6.2, 25% at 7.6, 50% at 9.9 and 100�/ at ECe 14.5 mmhos/cm. During germination the seedlings are about half as tolerant, which is relatively high compared to other crops.

Row spacing varies from 0.5 to 0.8 m, with 15 to 35 plants per metre of row. Seed rate for broadcast sowing of the irrigated crop is 40 to 50 kg/ha; for row crops, seed rate is 20 to 25 kg/ha.

The graph below depicts the crop stages of safflower, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalStage length, days202535353555455560 �253040125145190 �AprMarOct/Nov�California, USAHigh LatitudeArid RegionDepletion Coefficient, p----0.6�Root Depth, m----1.0�Crop Coefficient, Kc0.35>>1.0-1.1510.25-�Yield Response�Factor, Ky0.30.550.6-0.8The reputation of safflower as a drought resistant crop is mainly based on its ability to withdraw water from a depth of up to 3.5 m. It has proved, however, to have well-defined water requirements. For optimum crop yields, the total water requirements vary between 600 and 1200 mm depending on 'climate and length of total growing period. The crop water requirements (ETm) as related to reference evapotranspiration are given by the crop coefficients (kc): initial stage 0.3-0.4 (20 to 35 days); crop development stage 0. 7-0.8 (35 to 75 days); mid-season stage 1.05-1.2 (45 to 65 days); late season stage 0.65-0.7 (25 to 40 days) and at harvest 0.21-0.25.Following figure presents Safflower, spiny cultivar during flowering period (Weiss, 1971)

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of safflower are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Safflower is particularly susceptible to excess water because of its reaction to diseases under wet conditions. Excessive humidity, especially fog, induces head rot; excessive soil water causes root rot; excessive rain at flowering (period 2) adversely affects pollination and prevents complete seed filling which may not be noticeable in the field; excessive rainfall after the crop reaches maturity leads to seed germination in the head.

The relationships between relative yield reduction and relative evapotranspiration deficit based on interpreted information are shown in Figure 37. Water deficits during the early vegetative period (1a) and the late vegetative period (1b) cause a reduction in growth and prolong the total growing period. Safflower tolerates periods of water deficit but for maximum production flowering and yield formation (3) are the most sensitive periods to water deficit. Under conditions of limited water supply, overall production is increased by extending the area and partially meeting the crop water requirements rather than by meeting the full crop water requirements over a limited area.

For a 155-day total growing period the length of the different growth periods is:Crop stageDays0Establishment4-101aEarly vegetative (rosette development)251bLate vegetative (elongation and branching)602Flowering303Yield formation (seed filling)254ripening10Total150-160The rooting system of safflower is extensive and in deep soils roots may extend to 3.5m, but normally 100 percent of the water uptake of a full grown crop takes place from the first 1 to 2m (D = 1.0-2.0m). Under conditions when maximum evapotranspiration is 5 to 6mm/day, water uptake starts to be reduced when 60 per-cent of the total available soil water has been depleted.Irrigation scheduling should be aimed at minimizing excess soil water, particularly in relation to the sensitivity of the crop to root rot. A deep pre-planting irrigation is therefore very effective, followed by infrequent but heavy applications of water. Due to the deep rooting already during the early vegetative period (1a), the soil depth must be considered when deciding on the desirability of heavy watering.

In deep soils with high water holding capacity, usually two irrigation applications are sufficient, i. e. one before planting and one during flowering. However, a frequent mistake is a too early second application. On soils of lighter texture or when evapotranspiration demands are high, three-or more applications may be necessary.The crop is most commonly grown under surface irrigation, by the border method, allowing heavy irrigation applications. Also subirrigation is used and gives high yields.Under rainfed conditions good average yields vary from 2 to 3 ton/ha unshelled nuts under a high Under rainfed conditions yields depend on initial soil water storage and on the rainfall during the growing season. Good rainfed yields are in the range of 1 to 2.5ton/ha; under irrigation in the range of 2 to 4 ton/ha. The water utilization efficiency for harvested yield (Ey) for seed containing 8 to 10 percent moisture varies between 0.2 and 0.5 kg/m3.

The oil content varies from 20 to 40 percent depending on the variety and some recently developed Indian varieties may yield up to 50 percent oil. These new varieties are early maturing, more cold resistant and spineless, but are more susceptible to root rot and rust.

Time of picking depends on the use of the harvested product. Varieties with fruits of a high flesh/pit ratio and uniform shape are used for table olive production. In the northern hemisphere, green table olives are harvested from mid-September onward with end of harvest being determined when the fruit colour changes to green-yellow. Black table olives are harvested in December. Olives for oil are harvested from mid-December until March with oil content independent of the time of harvest.

Maximum oil content and weight are reached six to eight months after flowering. Olive fruits can be harvested long before they fall naturally.

Yields vary from year to year and from tree to tree. Good commercial yields under irrigation are 50 to 65 kg/tree of fruit with a possible maximum of 100 kg/tree of fruit. Oil content of the fresh fruit ranges from 20 to 25 percent. The water utilization efficiency for harvested yield (Ey) for fresh olives containing about 30 percent moisture is 1.5 to 2.0 kg/m3. � � � � � � � � � � � � � � � � � � � ��� � This section presents information on water relations and water management of soybean and provides links to other sources of information.Soybean (Glycine max) is one of the most important world crops and is grown for oil and protein. Present world production is about 176.6 million tons of beans over 75.5 million ha. The crop is mainly grown under rainfed conditions but irrigation, specifically supplemental irrigation, is increasingly used. (FAOSTAT, 2001).

The crop is grown under warm conditions in the tropics, subtropics and temperate climates. Soybean is relatively resistant to low and very high temperatures but growth rates decrease above 35�C and below 18�C. In some varieties, flowering may be delaXed at temperatures below 24�C. Minimum temp-eratures for growth are about 10�C and for crop production about 15�C. Only 25 to 30 percent of the flowers produce set pods, the final number depending on the plant vigour during the flowering period. Year to year temperature variations can lead to differences in flowering.

Soybean is basically a short-day plant, but response to daylength varies with variety and temperature and developed varieties are adapted only to rather narrow latitude differences. Daylength has an influence on the rate of development of the crop; in short-day types, increased daylength may result in the delay of flowering and taller plants with more nodes. Short days hasten flowering, particularly for late-maturing varieties. Vegetative growth normally ceases during yield formation. The length of the total growing period is 100 to 130 days or more. Soybean is often grown as a rotation crop in combination with cotton, maize and sorghum. Row spacing varies from 0.4 to 0.6 m with 30 to 40 seeds per metre of row.

The crop can be grown on a wide range of soils except those which are very sandy. Optimum soil pH is 6 to 6.5. The fertilizer requirements are 15 to 30 kg/ha P and 25 to 60 kg/ha K. Soybean is capable of fixing atmospheric nitrogen which meets its requirements for high yields. However, a starter dose of 10 to 20 kg/ha N is beneficial for good early growth.

A shallow water table, particularly during the early growth period can adversely affect yields. The plant is sensitive to waterlogging, but moderately tolerant to soil salinity. Yield decrease due to soil salinity is: 0% at ECe 5 mmhos/cm, 10% at 5.5, 25% at 6.2, 50% at 7.5 and 100% at ECe 10 mmhos / cm.

The graph below depicts the crop stages of soybean, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalStage length, days1520201530/3525406075�15253085140150��DecMayJuneTropicsCentral USAJapanDepletion Coefficient, p0.5>>0.60.90.5�Root Depth, m0.3>>>>1.0-�Crop Coefficient, Kc0.5>>1.150.5-�Yield Response�Factor, Ky0.20.8-1.00.85Water requirements (ETm) for maximum production vary between 450 and 700 mm/ season depending on climate and length of growing period. The water requirements are given by the crop coefficient (kc) in relation to reference evapotranspiration (ETo) and kc is: during the initial stage 0.3-0.4 (20 to 25 days), the development stage 0.7-0. 8 (25 to 35 days), the mid-season stage 1.0-1.15 (45 to 65 days), the late-season stage 0.7-0.8 (20 to 30 days) and at harvest 0.4-0.5.Following figure shows growth periods of soybean (after Chiang)

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Adequate water (between 15 and 50 percent soil water depletion) must be available for germination. Water deficiency or excess water during the vegetative period (1) will retard growth. Growth periods most sensitive to water deficits are the flowering (2) and yield formation periods (3), particularly the later part of the flowering period (end 2) and early part of the yield formation (pod development, 3a) period when water deficits may cause heavy flower and pod dropping. Irrigation after severe water deficits during period 2 may cause similar symptoms. The seeming drought-resistance of the-crop during flowering (2) and early yield formation (pod development, 3a) is the result of the flowering period extending over one month; light water deficits during a part of this period can be compensated for by better retention of later-formed flowers and pod setting. For normal pod filling and high yield the soil water during the yield formation period (pod filling, 3b) should not exceed the 50 percent depletion level.

When water supply is limited, savings in water can be made by reducing the supply during the vegetative period (1) and particularly near crop maturity (late 4). When required, a pre-irrigation should be given to allow proper crop establishment. Water savings should be minimal during the late flowering period (late 2) and early yield formation period (pod development, 3a).

For maximum production, water supply may be directed toward enlarging the area under irrigation rather than toward meeting maximum crop water requirements over a restricted acreage. However, crop water demands should be met during the establishment period (0) and early yield formation (3a).Depending on soil water availability, early root development in deep soils is relatively rapid and vigorous. Most rapid root growth is often noted after the start of flowering. The tap root may extend to over 1.5 m. The crop can effectively draw all available soil water up to 1.8 m. If soil depth is restricted, the tap root is less pronounced and lateral roots are more developed. While the crop can grow on heavy soils, the roots tend not to penetrate even moderately compacted layers. Although the roots are generally concentrated in the first 0.6 m or even sometimes the first 0.3 m, considerable soil water, particularly during the later growth periods, can be extracted from the lower parts of the root zone. However, under normal conditions 100 percent of the water uptake occurs from the first 0.6 to 1.3 m soil depth (D = 0.6-1.3 m).

At germination, the soil water content should not exceed 85 percent or fall below 50 percent of available soil water. After establishment (0), the crop can withstand short periods of drought. For irrigation scheduling under medium evaporative conditions (ETm 5 to 6 mm/day), an allowable depletion level of 55 percent may be assumed (p = 0.55)Soybean is usually not grown under full irrigation. In many climatic conditions, however, one or more supplemental irrigations during critical growth periods will substantially increase yields. If one application can be given, the most likely timing will be in the late flowering period (2), when small pods are beginning to appear. If two applications can be given, it is usually wise to give the first application at pre-emergence to assure a rapid establishment of the plant. A third application, where possible, will give the best results if given at the beginning of pod filling (3b).In areas where soybean is irrigated, the costs of sprinkler irrigation only can be borne if it is grown in rotation with high value crops. Furrow irrigation is most common.Yield can vary widely with water availability, fertilization and row spacing. Under rainfed conditions, good soybean yields vary between 1.5 and 2.5 ton/ha seed. High yields of improved varieties are between 2.5 and 3.5 ton/ha seed under irrigation. The water utilization efficiency for harvested yield (Ey) for seed containing 6 to 10 percent moisture is 0.4 to 0.7 kg/m3. The effect of irrigation on oil and protein content of the grain is rather insignificant. However, under adequate irrigation there is a tendency toward a slight increase in protein content and a slight decrease in oil content. � � ��� � This section presents information on water relations and water management of sunflower and provides links to other sources of information.Sunflower (Helianthus annuus) originates from central and north America. Lately its importance as an oil crop has grown and at present it is tile second most important oil crop next to soybean. Total annual world production is some 20.9 million tons of seed from some 18 million ha.(FAOSTAT, 2001).

Sunflower thrives in climates ranging from arid under irrigation to temperate under rainfed conditions, but is susceptible to frost. Mean daily temperatures for good growth are between 18 and 25�C. The total growing period varies from 70 days in parts of Russia where the season is short to 200 days at higher altitudes in Mexico. In the subtropics under irrigation the total growing period is about 130 days. For temperate climates the optimum planting date for early as well as late maturing varieties is between late spring and early summer. Delay in planting results in shortening of the vegetative period and early maturity, causing a decrease in head diameter and seed weight. Sunflower is a short-day plant with a variable response to daylength, but day-neutral varieties exist.

The crop is mainly grown under rainfed conditions on a wide range of soils. Under erratic and low rainfall, a rather deep soil with good water holding capacity is required. Due to its deep root system (2 to 3m) soil water can be explored at great depths. Optimum soil pH is in the range of 6.0 to 7.5, but at lower values liming may be necessary. Fertilizer application is in general 50 to 100 kg/ha N, 20 to 45 kg/ha P and 60 to 125 kg/ha K. The crop is particularly sensitive to boron deficiency.

Optimum plant density is about 60 000 plants/ha with row spacing of about 0.9 m; seed rate is between 4 and 10 kg/ha. Both transplantation and direct seeding are practised.

In the major sunflower growing areas salinity problems are minor; an indication of tolerance to salinity during crop establishment is shown by the emergence percentage of seedlings which is 80 to 100% at ECe 0.70 to 75% at 4.5, 30 to 60% at 9.5, 15 to 55% at 10 and 0 to 25% at ECe 13 mmhos/cm. However, in later growth periods sunflower is moderately tolerant to salinity.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalStage length, days253545�25130 �Apr/MayMediterranean.,CaliforniaDepletion Coefficient, p0.55>>0.50.80.45�Root Depth, m0.3>>>>1.3-�Crop Coefficient, Kc0.35>>1.0-1.1510.35-�Yield Response�Factor, Ky0.250.50.81.00.951The lower values are for rainfed crops having less dense plant populationThe water requirements of sunflower vary from 600 to 1000 mm, depending on climate and length of total growing period. Evapotranspiration increases from establishment to flowering, and can be as high as 12 to 15 mm/day. High evapotranspiration rates are maintained during seed setting and early ripening period. Percentage of total crop water use over the different growth periods is about 20 percent during vegetative period, 55 percent during the flowering period and the remaining 25 percent during the yield formation and ripening periods. The crop coefficient (kc) is 0.3-0.4 during the initial stage (20 to 25 days), 0.7-0.8 during the crop establishment stage (35 to 40 days), 1.05-1.2 during the mid-season stage (40 to 50 days), 0.7-0.8 during the late-season stage (25 to 30 days) and 0.4 at maturity or harvest.Following figure shows growth periods of sunflower (after Siddigue et al.)

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

In respect of total yield produced, water requirements of sunflower are relatively high compared to most crops. Despite its high water use, the crop has an ability to withstand short periods of severe soil water deficit of up to 15 atmosphere tension. Long periods of severe soil water deficit at any growth period cause leaf-drying with subsequent reduction in seed yield. With heavy rain or irrigation following an extremely dry period, only a partial recovery occurs.

Severe water deficits during the early vegetative period (1a) result in reduced plant height but may increase root depth. Adequate water during the late vegetative period is required for proper bud development (1b). The flowering period (2) is the most sensitive to water deficits which cause considerable yield decrease since fewer flowers come to full development. Yield formation (3) is the next most sensitive period to water deficit, causing severe reduction in both yield and oil content.In deep soils the root system of sunflower may extend up to 2 to3m but normally, when the crop is full grown, 100 percent of the water is extracted from the first 0.8 to 1.5m (D = 0.8-1.5m). Under conditions when maximum evapotranspiration is 5 to 6 mm/day, the water uptake is affected when about 45 percent of the total avail-able soil water is depleted (p = 0.45)For high production, soil water depletion should not exceed 45 percent of the available soil water, particularly during the late vegetative, flowering and yield formation periods. Due to the deep root system, 2 to 4 heavy irrigation applications are usually sufficient when the crop is grown on deep, medium textured soils. In addition a pre-irrigation is given when required. Application should be scheduled during the late vegetative (1b) and the flowering (2) periods. When water supply is limited, water savings can be made during the ripening period (4).The crop is most suited to surface irrigation, particularly by furrow irrigation, allowing infrequent and heavy application.The giant varieties, grown for poultry feeding and human consumption because of their low oil content, produce seed yields in the range of 0.8 to 1. 5 ton/ha under rainfed conditions. The seeds of dwarf and semi-dwarf varieties contain 25 to 35 percent oil and give a total yield similar to the giant varieties. New Russian varieties with seeds of low hull content have an oil content of up to 50 percent. Under irrigation seed yields of 2.5 to 3.5 ton/ha are commonly obtained. The water utilization efficiency for harvested yield (Ey) for seeds containing 6 to 10 percent moisture is 0.3 to 0.5 kg/m3. ��� � This section presents information on water relations and water management of bean and provides links to other sources of information.Common bean (Phaseolus vulgaris) is known under different names (French bean, kidney bean, snap bean, runner bean, string bean). It can be grown as a vegetable crop for fresh pods or as- a pulse crop for dry seed. World production of dry beans is about 16.7 million tons from about 23 million ha and green beans 4.7 million tons from 0.7 million ha (FAOSTAT, 2001).

Common bean grows well in areas with medium rainfall, but the crop is not suited to the humid, wet tropics. Excessive rain and hot weather cause flower and pod drop and increase the incidence of diseases. Optimum mean daily temperatures range between 15 and 20�C. The minimum mean daily temperature for growth is l0�C, the maximum 27�C. High temperatures increase the fibre content in the pod. Germination requires a soil temperature of 15�C or more, and at 18�C germination takes about 12 days, and at 25�C about 7 days. Most bean varieties are not affected, by daylength. The length of the total growing period varies with the use of the product and is 60 to 90 days for green bean and 90 to 120 days for dry bean.

The crop does not have specific soil requirements but friable, deep soils with pH of 5.5 to 6.0 are preferred. Fertilizer requirements for high production are 20 to 40 kg/ha N, 40 to 60 kg/ha P and 50 to 120 kg/ha K. Bean is capable of fixing nitrogen which can meet its requirements for high yields. However, a starter dose of N is beneficial for good early growth. The crop is sensitive to soil-borne diseases and should be grown in a rotation; in the subtropics in the USA wheat, sorghum, onion and potato are common rotation crops, whereas in tropical Africa and Asia maize, sweet potato and cotton are common.

Normal sowing depth is about 5 to 7 cm. Spacing depends on variety. Bush types (erect) normally have a plant and row spacing of 5 to 10 x 50 to 75 cm, while pole-type (climbing) are 10 to 15 x 90 to 150 cm. Pole beans are also often grown on hills spaced 90 to 120 cm apart. Other spacings are possible, and these depend on the method of harvest.

Common bean is sensitive to soil salinity. The yield decrease at different levels of ECe is:0% at ECe 1.0, 10% at 1.5, 25% at 2.3, 50% at 3.6 and 100% at ECe 6.5 mmhos/cm.

The graph below depicts the crop stages of bean, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalBeans - dryStage length, days201525302525403530� �2020201109510O� �May/JuneJuneJune� �Continental ClimatePakistan, Calif.Idaho, USA�Depletion Coefficient, p0.45>>0.450.6-�Root Depth, m0.30>>>>1.0-�Crop Coefficient, Kc0.4>>1.150.35-�Yield Response Factor, Ky0.21.10.750.21.5�Bean-freshStage length, days�2015302530�25 �101090�75 �Feb/MarAug/SepCalif., MediterraneanCalif., Egypt, Lebanon�Depletion Coefficient, p0.45>>0.450.6�Root Depth, m0.30>>>>1.0-�Crop Coefficient, Kc0.5>>1.050.9-�Yield Response Factor, Ky0.21.10.750.41.15�Water requirements for maximum production of a 60 to 120-day crop vary between 300 and 500 mm depending on climate. The water requirement's during the ripening period depend very much on whether the pod is harvested wet or dry. When grown for its fresh product, the total growing period of the crop is relatively short and during the ripening, which is about 10 days long, the crop evapotranspiration is relatively small because of the drying of the leaves. When the crop is grown for seed the ripening period is longer and the decrease in crop evapotranspiration is relatively greater. The growing period depends on the number of pickings, and when 3 or 4 pickings are taken the harvest period is 20 to 30 days. Crop coefficient (kc) relating reference evapotranspiration (ETo) to water requirements (ETm) for different development stages is, for common bean, green: during the initial stage 0.3-0.4 (15 to 20 days); the development stage 0.65-0.75 (15 to 20 days); the mid-season stage 0.95-1.05 (20 to 30 days); the late-season stage 0.9-0.95 (5 to 20 days) and at harvest 0.85-0.9. For common bean, dry, the kc value is: during the initial stage 0.3-0.4 (15 to 20 days); the development stage 0.7-0.8 (15 to 20 days); the mid-season stage 1.05-1.2 (35 to 45 days); the late-season stage 0.65-0.75 (20 to 25 days); and at harvest 0.25-0.3.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Water supply needed for maximum yield for both fresh and dry produce is similar during much of the growing period but varies during the ripening period. For green beans supply is continued just prior to the last picking, but for dry bean it is discontinued about 20 to 25 days before crop harvest. With one picking only the harvest period is concentrated. This can be achieved to some extent by the timing of water supply so as to induce a slight water deficit to the crop during the ripening period and a soil water depletion to about 50 percent of the total available water may hasten the onset of maturity. Concentration of the harvest period is more easily achieved for bush than for pole types. The former normally have a more uniform ripening period.green beandry bean0establishment10-15 days10-15 days1vegetative (up to first flower)20-2520-252flowering (including pod setting)15-2515-253yield formation (pod development and bean filling)15-2025-304ripening0-520-2560-9090-120 daysHowever, a severe water deficit during the vegetative period (1) generally retards plant development and causes non-uniform growth.

During flowering (2) and yield formation (3) frequent irrigation results in the highest 'response to production, although excess water increases the incidence of diseases, particularly root rot. When nitrogen is supplied to the crop in the form of mineral fertilizer, irrigation should be accompanied by adequate application of nitrogen fertilizer in order to maximize yield.

When water supply is limited, some water savings could be made during the vegetative period (1) and, for dry bean, also. during the ripening period without greatly affecting yield, provided water deficits are moderate. Total production is higher when full crop water requirements are met over a limited area then when the cultivated area is extended under limited supply conditions.The tap root of the bean plant may reach a depth of 1 to 1.5 m. The lateral root system is extensive and is mainly concentrated in the first 0.3 m. At emergence, the rooting depth is about 0.07 m, at the start of flowering 0.3 to 0.4 m, and at maturity 1 to 1.5 m. Water uptake occurs mainly in the first 0.5 to 0.7 m depth (D = 0.5-0.7 m). Under conditions when ETm is 5 to 6 mm/day, 40 to 50 percent of the total available soil water can be depleted before water uptake is affected (p = 0.4-0-5).When the bean crop is grown with supplemental irrigation, water supply should be directed toward meeting water requirements during the establishment period (0) and the early part of the flowering period (2). When the crop is grown under full irrigation, the soil water depletion during the flowering (2) and yield formation (3) periods should not exceed 40 to 50 percent of the total available soil water (p = 0-4-0.5). When the crop is grown for dry seed the depletion level during the ripening period (4) should not exceed 60 to 70 percent. Water stress in the plant can be detected by eye because the leaves turn dark bluish-green in colour.Water deficit during the yield formation period (3) gives rise to small, short discoloured pods with malformed beans. Also, the fibre content of the pods is higher and seeds lose their tenderness. Good commercial yield in favourable environments under irrigation is 6 to 8 ton/ha fresh and 1.5 to 2 ton/ha dry seed. The water utilization efficiency for harvested yield (Ey) for fresh bean containing 80 to 90 per-cent moisture is 1.5 to 2.0 kg/m3 and for dry bean containing about 10 percent moisture, 0.3 to 0.6 kg/m3. ��� � This section presents information on water relations and water management of pea and provides links to other sources of information.Pea (Pisum sativum) is grown as a vegetable crop for both fresh and dried seed. Present world production is about 10.5 million tons dry pea and 7 million tons fresh pea.(FAOSTAT, 2001).

The varieties range from tall climbing to small bunch types with the latter having a shorter growing period. Pea is a cool climate crop and optimum mean daily temperature is 17�C with a minimum of 10�C and a maximum of 23�C. Germination is affected by soil temperature; at 5�germination takes 30 days or more, at l0�C about 14 days and at 20 to 30�C about 6 days. Young plants can tolerate light frost but flowers and green pods are injured by light frost. In the tropics near the equator, peas are grown at about 1500 m altitude, or as a winter crop in areas away from the equator. The normal growing period is 65 to 100 days for fresh pea with an additional 20 days for dry peas. The growing period is extended under cool conditions.

The crop does well on most soils with good drains e and pH of 5.5 to 6.5. Fertilizer requirements are about 20 to 40 kg/ha N, 40 to & kg/ha P and 80 to 160 kg/ha K. Pea is capable of fixing atmospheric nitrogen, which meets its requirements for high yields. However, a starter dose of 20 to 40 kg/ha N is beneficial for good early growth.

Pea is sensitive to soil salinity with yield decrease at different levels of ECe similar to that of bean, or 0% at ECe 1.0, 10% at 1.5, 25% at 2.3, 50% at 3.6, and 100% at ECe 6.5 mmhos/cm.

Plant spacing depends on variety and type and whether bunch or climbing, and is between 0.6 to 0.9 x 0.05 to 0.1 m with a wider spacing when grown along with stakes. Depth of sowing is 2 to 5 cm. Prevention against root rot requires good drainage and rotation. Common rotation crops are alfalfa, potatoes and sugarbeet.

The graph below depicts the crop stages of pea, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalPea-dryStage length, days15203525302535353O� �15152090100110� �MayMarch/AprilApril� �EuropeMediterraneanIdaho, USADepletion Coefficient, p----0.4�Root Depth, m----1.0�Crop Coefficient, Kc0.5>>1.150.3-�Yield Response Factor, Ky0.20.90.70.21.15�Pea-freshStage length, days152035253025353530��15152090100110��MayMarch/AprilAprilEuropeMediterraneanIdaho, USA�Depletion Coefficient, p----0.35�Root Depth, m----1.0�Crop Coefficient, Kc0.5>>1.151.1-�Yield Response Factor, Ky0.20.90.70.21.15�Water requirements (ETm) of pea are similar to bean (350 to 500 mm). The crop coefficient (kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is: during the initial stage 0.4 (10 to 25 days), the development stage 0.7-0.8 (25 to 30 days), the mid-season stage 1.05-1.2 (25 to 30 days), the late-season stage 1.0-1. 15 (5 to 10 days) (fresh) and 0.65-0.75 (20 to 30 days) (dried), and at harvest 0.95-1.1 (fresh) and 0.25-0.3 (dried).The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

The growing periods of pea are:Crop stageFreshFlower0establishment10-15 days10-15 days1vegetative25-3025-302flowering (including pod set)15-2015-203yield formation (pod development and bean pod)15-2020-254ripening0-515-20Total65-100 days85-120 daysThe sensitive periods for water deficits are flowering (2) and yield formation (3). Unlimited water supply during the vegetative period (1) increases vegetative growth but may not necessarily affect the pea yield; water deficit in this period has a relatively small effect on yield. Similarly, water deficit during the ripening period for dry peas has a small effect on yield.

When rainfall is insufficient, irrigation during the flowering period (2) increases the number of marketable pods and number of seeds per pod, and during the yield formation period (3) increases the weight of both pod and seed. The crop tends to wilt more readily during periods of water shortage when adequate water was avail-able in the preceeding periods.

For high yields the soil water depletion should not exceed 60 percent of the total available soil water during the vegetative period (1), and 40 percent during flowering (2) and yield formation (3) periods. Too frequent and light irrigation application results in uneven ripening. With harvest consisting of one picking it is some-times recommended to withhold water supply during the latter part of the yield formation period (3) to advance ripening of the most developed pods. This applies particularly to varieties with a long and non-uniform ripening period.

Under conditions of limited water supply a high total production is obtained by meeting full crop water requirements on a limited area rather than by extending the area and partially meeting crop water requirements.The crop has a tap root with many thin laterals. Rooting depth in deep soils can extend to 1 to 1. 5 m but the effective depth of water uptake is generally restricted to the first 0.6 to 1.0 m (D=0.6-1.0m). The uptake pattern over soil depth, however, depends greatly on the irrigation practices. The uptake of water in relation to ETm is little affected up to soil water depletion of about 40 percent of total available soil water (p = 0.4).For optimum yield levels the soil water depletion in most climates should not exceed 40 percent of the total available soil water and irrigation frequencies of 7 to 10 days are common. When water supply is short, irrigation should be adequate during the flowering (2) and yield formation (3) periods with possible savings during the vegetative (1) and ripening (4) periods. When frequent irrigation is not possible, water supply should be scheduled as pre-irrigation, at flowering (2) and at the yield formation period (3) respectively, or with one irrigation only at least about 40 to 60 days after the pre-irrigation.When irrigation is irregular, pods and seeds are less uniform in size, more variable in colour and also the date of maturity will vary. A high water deficit during late yield formation results in tough seeds of poor quality. In general, increase in seed size is accompanied by a decrease in the sugar content and the tenderness of the seed, and an increase in the starch and protein contents. Correct timing of the harvest remains an essential requirement for a good quality product. In suitable climates, good yields under irrigation are between 2 and 3 ton/ha shelled fresh pea (70 to 80 percent moisture) and 0.6 and 0.8 ton/ha dry pea (12 percent moisture). The water utilization efficiency for harvested yield (Ey) for fresh pea is about 0.5 to 0.7 kg/m3 and for fresh pea about 0. 15 to 0.20 kg/m3. � � � � � � � � � � � � � � � � � � � � ��� � This section presents information on water relations and water management of sugarbeet and provides links to other sources of information.Sugarbeet (Beta vulgaris) provides about 16 percent of the world's sugar production. Present world production is about 234 million tons of beets from about 5.9 million ha. (FAOSTAT, 2001).

The crop is believed to originate from Asia. Sugarbeet is a biennial crop but for sugar production beets are harvested in the first year. Flowering occurs during the second year. The crop is grown under rainfed conditions but also widely under irrigation in the subtropics where the crop is known for its high tolerance to saline and alkali soils.

The crop needs a relatively long growing period, normally from 140 to 160 up to 200 days. Large amounts of sugar are formed in the leaves.

The greater part is used for growth processes during the vegetative period, while in the late growing period when vegetative growth slows down a large part is stored in the roots. However, sugar yield is determined by both root size and sugar concentration. With rapid growth of the storage root the sugar concentration reaches a steady value which is principally determined by climate, water supply and nitrogen level in the soil and is influenced to some extent by variety and plant spacing. Sugar percentage in the root is often greater than 15 percent of the fresh root weight. The crop is harvested toward the end of the first season's growth, when the roots contain maximum amount of sugar.

The crop is grown in different climates. Seed germination is possible at 5�C but the effective minimum is considered to be 7 to 10�C. Higher temperatures during vegetative growth are preferred, but high sugar yields are obtained when night temperatures are between 15 and 20�C and day temperatures between 20 and 25�C during the latter part of the growing period. During this period temperatures greater than 30�C greatly decrease sugar yields. For high sugar yields and low vegetative growth in the latter part of the growing period, progressively cooler nights should be accompanied by an exhaustion of available soil nitrogen and soil water.

When the crop is grown for seed, several weeks at low temperatures, near 4�C, are required to induce flowering, which tends to be accelerated by long days.

The crop can be grown on a wide range of soils with medium to slightly heavy textured, well-drained soils preferred. Restricted deep root growth in the early part of the growing period due to soil compaction may result in formation of forked and sprangled roots with reduced yields. Soil pH smaller than 5.5 is unfavourable to growth. Crust forming at the soil surface at the time of germination can lead to poor crop stand.

Adequate nitrogen is required to ensure early maximum vegetative growth. Nitrogen is often given in split applications, a small amount at planting and the rest after thinning. Nitrogen either in an excessive amount or when applied late during the growing season reduces sugar content. Fertilizer applications may be up to 150kg/ha N, 50 to 70kg/ha P at planting and 100 to 160kg/ha K.

A deep, well-prepared seedbed is advantageous. Seeds are planted 1 to 2 cm deep in single or double rows, with width between single rows 0.5 to 0.7m and double rows about 1m. When the plant has 4 to 8 leaves, thinning, by hand or by machine, is frequently needed to space 3 to 6 beets per metre row. Seed rates vary between 12 and 30kg/ha. Plant densities under commercial production vary from 40 000 up to 100 000 plants/ha.

Except during the early stages, after crop establishment, the crop is tolerant to salinity. Yield decrease is 0% at ECe 7, 10% at 8.7, 25% at 11, 50% at 15 and 100% at ECe 24 mmhos/cm. During early growth ECe should not exceed 3 mmhos/cm.

The graph below depicts the crop stages of sugarbeet, and the table summarises the main crop coefficients used for water management.Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days�302525502545354530654035756090901005050807015106540503040180155255180160230205MarchJuneSepAprilMayNov.Nov.(Calif., USA�Calif., USA�Calif. Desert, USA�Idaho, USA�MediterraneanMediterraneanArid RegionsDepletion�Coefficient, p:0.5>>0.60.60.551Root Depth, m0.3>>>>1.0-Crop Coefficient,Kc0.35>>1.20.72-��Yield Response�Factor, KyRoot YieldSugar Yield--------1.11.0��1�Sugarbeet often experience late afternoon wilting in arid climates even at p < 0.55, with usually only minor impact on sugar yield.2�The Kcend (or late) value is for no irrigation during the last month of the growing season. the Kcend (or late) for sugarbeets is higher, up to 1.0, when irrigation or significant raim occurs during the last month.For maximum production, water requirements of the crop are related to reference crop evapotranspiration (ETo). The crop coefficient (kc) is 0.4-0.5 during the initial stage (25 to 30 days), 0. 75-0.85 during the crop development stage (35 to 60 days), 1.05-1.2 during mid-season stage (50 to 70 days), 0.9-1.0 during the late-season stage (30 to 50 days) and 0.6-0.7 at time of harvest. Total water requirements are in the range of 550 to 750 mm/growing period, but vary with climate and length of the total growing period. Time of sowing affects the rate of crop development, particularly from emergence to when the crop has reached its maximum height, which for an autumn-sown crop may be 140 days, for a spring-sown crop about 90 days and for a late spring/early summer-sown crop about 60 days.Following figure shows the duration of the different growth periods of the sugarbeet crop with 140 to 200 day growing period (after G.B. Heathcots)

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of root yield are shown in the figure below.

The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of sugar yield are shown in the figure below.

When grown for sugar, flowering and seed production is avoided. Sugarbeet is particularly sensitive to water deficits at the time of crop emergence and a period of about a month after emergence (0). Frequent, light irrigations are preferred during this period, and irrigation may also be needed to reduce crust formation on the soil and to reduce salinity of the top soil. Early over-watering may retard leaf development and can encourage flowering during the first year (bolting).

Water deficits in the middle part of the growing period (vegetative and yield formation periods, 1 and 3) tend to affect sugar yields more strongly when occurring during later periods. Ample supply in the later part of the growing period (ripening period, 4) has an adverse effect on sugar concentration although it may increase the root size, with the final effect on yield being small. Water deficits together with a nitrogen deficiency toward the end of the growing period lead to a reduction in root growth but an increase in sugar concentration. In general, top growth toward the end of the growing period tends to be negatively correlated with sugar production. Irrigation supply must be discontinued at least 2 to 4 weeks prior to harvest.

Thus, except during emergence and early growth periods, it appears that the crop is less sensitive to moderate water deficits. The effect of reduced water supply over the total growing period is often masked by the overriding influence of temperature, nitrogen availability and reduced water needs during a period just prior to harvest.

When available water resources are limited and when maximum overall production is aimed at, water supply should be directed toward expanding the area under irrigation rather than concentrating the supply over a limited area to meet maximum water requirements (ETm) over the total growing period. This is because there is an increase in the efficiency of water utilization (Ey) for both roots and sugar yield when water supply is reduced so that yields decrease less than proportionally with the reduction of water supply (ky< 1) provided the growing environment during the later part of the growing period is favourable to sugar storage.In deep soils the crop can develop a deep tap root system but normally 100 percent of the water is extracted from the first 0.7 to 1.2m soil depth (D = 0.7-1.2m). Under conditions when ETm is 5 to 6mm/day, 50 to 60 percent of the total available soil water can be depleted without reducing water uptake (p = 0. 5-0.6), with higher depletion levels just before harvest. When the plant is under water stress the leaves become dark green in colour and when the water stress is severe the leaves fail to recover from midday wilting in the evening.Frequent, light irrigations during the establishment period (0) are advantageous and sufficient soil water must be available at emergence. An irrigation is frequently applied after thinning. Irrigation intervals can be selected using Table 21. The irrigation is discontinued at least 2 to 4 weeks before harvest to increase sugar concentration in the beets. The soil should, however, not be too dry to hamper lifting of the beets at harvest.The most common method is furrow irrigation. Border irrigation is sometimes practised but it is not common. Sprinkler irrigation offers advantages particularly during the germination and emergence period when frequent but light applications may be adequate. However, young plants will be damaged when sprinkling with poor quality (saline) water.A good commercial yield of 160 to 200 day sugarbeet is 40 to 60 ton/ha of fresh beet at 15 percent sugar. Under certain conditions yields of up to 70 to 80 ton/ha are obtained. The water utilization efficiency for harvested yield (Ey) for beets containing 80 to 85 percent moisture is 6 to 9 kg/m3�and for sucrose containing no moisture 0.9 to 1.4 kg/m3.

A few comparative studies have been made between sugarbeet and sugarcane performance. For a given location, climate is the most important factor in dictating which crop is likely to be more suitable from the point of view of production. ��� � This section presents information on water relations and water management of cabbage and provides links to other sources of information.Cabbage (Brassica oleracea var. capitata) originates from the south and western coast of Europe. Annual world production is about 55 million tons of fresh heads from 2.6 million ha (FAOSTAT, 2001).

For high production the crop requires a cool, humid climate. The length of the total growing period varies between 90 (spring-sown) and 200 (autumn-sown) days, depending on climate, variety and planting date, but for good production the growing period is about 120 to 140 days. Most varieties can withstand a short period of frost of -6�C, some down to -10�C. Long periods (30 to 60 days) of -5�C are harmful. The plants with leaves smaller than 3 cm will survive long periods of low temperature but when the leaves are 5 to 7 cm, the plant will initiate a seed stalk and this leads to a poor quality yield. Optimum growth occurs at a mean daily temperature of about 17�C with daily mean maximum of 24�C and minimum of 10�C. Mean relative humidity should be in the range of 60 to 90 percent.

Generally, the heavier loam soils are more suited to cabbage production. Under high rainfall conditions, sandy or sandy loam soils are preferable because of improved drainage. The fertilizer requirements are high: 100 to 150 kg/ha N, 50 to 65 kg/ha P and 100 to 130 kg/ha K.

Cabbage is moderately sensitive to soil salinity. Yield decrease due to soil salinity at different levels of ECe is: 0% at ECe 1.8, 10% at 2.8, 25% at 4.4, 50% at 7.0 and 100% at ECe 12.0 mmhos/cm.

Row spacing is dependent on the size of heads required for markets or between 0.3 and 0.5 m for heads of 1 to 1.5 kg each and 0.5 and 0.9 m for heads up to 3 kg each. An optimum production can be reached with a plant density in the range of 30000 to 40000 plants/ha. Planting can be by direct seeding with a seed rate of 3 kg/ha, or by transplanting from open field beds and from cold frames which are used to protect the crop from cold during germination and early plant development.

Cabbage is characterized by slow development during the first half of the growing period, which may be 50 days for early maturing and up to 100 for autumn-sown, late maturing varieties (establishment and vegetative periods; 0 and 1). During the following periods (yield formation and ripening periods, 3 and 4) the plant doubles its weight approximately every 9 days over a total period of 50 days. In the beginning of the yield formation period (3), head formation starts, followed by a sudden decrease in the rate of leaf-unfolding. Eventually, leaf unfolding ceases completely, whilst leaf initiation continues. This results in the formation of a restrictive skin by the oldest folded leaves within which younger leaves continue to grow until the firm, mature head is produced during the ripening period of 10 to 20 days (4). Depending on variety, the head can be pointed or round, green or red, smooth or crinkled. Crop rotation of at least 3 years is recommended to combat soil-borne diseases.

Full-grown Cabbage The graph below depicts the crop stages of cabbage, and the table summarises the main crop coefficients used for water management.Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days�40605015165SeptemberCalf. Desert, USADepletion�Coefficient, p:0.4>>0.40.4-Root Depth, m0.25>>>>0.5-Crop Coefficient,Kc0.7>>1.050.95-��Yield Response�Factor, Ky0.2-0.450.60.95��Water requirements vary from 380 to 500 mm depending on climate and length of growing season. The crop transpiration increases during the crop growing period with a peak toward the end of the season. In relation to the reference evapotranspiration (ETo), the crop coefficient (kc) for cabbage is: during the initial stage 0.4-0.5 (20 to 30 days); the crop development stage 0.7-0.8 (30 to 35 days); the mid season stage 0.95-1.1 (20 to 30 days), the late season stage 0.9-1.0 (10 to 20 days); and at harvest 0.8-0.95.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.

� This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

The relationships between relative yield decrease and relative evapotranspiration deficit based on interpreted information are given in Figure 12. The response to water supply increases with development of the crop. During the slow development in the vegetative period (1), the crop yield is little affected by water deficit. Once rapid growth during yield formation period (3) is reached, the yield depressing effect of limited water supply becomes increasingly pronounced until the end of the growing period. Under conditions of limited water supply, a high total production is obtained by extending the area and partially meeting crop water requirements rather than by meeting full crop water requirements over a limited area.Cabbage has an extensive, shallow root system. The majority of the roots are found in the top 0.4 to 0.5 m of the soil with a rapid decrease in root density with depth. Normally 100 percent of the water is extracted from this layer (D = 0.4-0.5 m). Under conditions when ETm = 5 to 6 mm/day, the rate of water uptake by the crop starts to reduce when the available soil water has been depleted by about 35 percent (p = 0.35).Depending on climate, crop development and soil type, the frequency of irrigation varies between 3 and 12 days. If available water supply is limited, early irrigations should not be practised unless these can be continued until the end of the crop growing period. Water savings should preferably be made in the beginning of the crop growing period.Furrow, sprinkler and trickle irrigation are used. However, the acreage under subsoil irrigation, which gives generally better results, is -increasing. With subsoil irrigation, the depth of the water table is maintained between 0.3 and 0.7 m in fine, sandy loam and between 0.7 and 1. 1 m in loam soils.Under rainfed conditions, yields of 25 to 35 ton/ha fresh heads are normal, with a maximum of about 50 ton/ha when sprayed and well-fertilized. Under ideal climatic conditions and good irrigation and crop management, yields can be as high as 85 ton/ha. The utilization efficiency for harvested yield (Ey) for heads is about 12 to 20 kg/m3.

The average water content of cabbage heads is about 90 percent, with a high vitamin B, C and calcium and phosphorous content. Smaller heads of poor quality are produced when the crop is grown under limited water supply, particularly during the later part of the growing period. ��� � This section presents information on water relations and water management of onion and provides links to other sources of information.Onion (Allium cepa) is believed to have originated in the Near East. The crop can be grown under a wide range of climates from temperate to tropical. Present world production is about 46.7 million tons of bulbs from 2.7 million ha (FAOSTAT, 2001).

Under normal conditions onion forms a bulb in the first season of growth and flowers in the second season. The production of the bulb is controlled by daylength and the critical daylength varies from 11 to 16 hours depending on variety. The crop flourishes in mild climates without extremes in temperature and without excessive rainfall. For the initial growth period, cool weather and adequate water is advantageous for proper crop establishment, whereas during ripening, warm, dry weather is beneficial for high yield of good quality. The optimum mean daily temperature varies between 15 and 20�C. Proper crop variety selection is essential, particularly in relation to the daylength requirements; for example, a long day temperate variety in tropical zones with short days will produce vegetative growth only without forming the bulb. The length of the growing period varies with climate but in general 130 to 175 days are required from sowing to harvest.

The crop is usually sown in the nursery and transplanted after 30 to 35 days. Direct seeding in the field is also practised. The crop is usually planted in rows or on raised beds, with two or more rows in a bed, with spacing of 0.3 to 0.5 x 0.05 to 0.1 m. Optimum soil temperature for germination is 15 to 25�C. For bulb production the plant should not flower since flowering adversely affects yields. Bulbs are harvested when the tops fall: For initiation of flowering, low temperatures (lower than 14 to 16�C) and low humidity are required. Flowering is, however, little affected by daylength.

Onion can be grown on many soils but medium textured soils are preferred. Optimum pH is in the range of 6 to 7. Fertilizer requirements are normally 60 to 100 kg/ha N, 25 to 45 kg/ha P and 45 to 80 kg/ha K.

The crop is sensitive to soil salinity and yield decrease at varying levels of ECe is: 0% at ECe 1.2 mmhos/cm, 10% at 1.8, 25% at 2.8, 50% at 4.3 and 100% at ECe 7.5 mmhos/cm

The following figure shows an onion plant during the yield formation period (3)

The graph below depicts the crop stages of onion, and the table summarises the main crop coefficients used for water management.

Stages of DevelopmentPlant dateRegionCrop�characteristicInitialCrop�DevelopmentMid-seasonLateTotalOnion - dryStage length, days15202535701104045150210AprilOct./Jan�MediterraneanArid Region; Calif.�Depletion Coefficient, p----0.3Root Depth, m----0.6Crop Coefficient, Kc0.7>>1.050.75-Yield Response Factor, Ky0.45-0.80.31.1Onion - GreenStage length, days25203030455510205551040709518OAprilOctoberMarch�Mediterranean�Arid RegionCalif., USADepletion Coefficient, p----0.3�Root Depth, m----0.6�Crop Coefficient, Kc0.7>>1.01.0-�Onion - SeedStage length, days204516545275SeptemberCalif., Desert,�USADepletion Coefficient, p---

-0.35�Root Depth, m----0.6�Crop Coefficient, Kc0.7>>1.050.8-�For optimum yield, onion requires 350 to 550 mm water. The crop coefficient (kc) relating reference evapotranspir ation (ETo) to water requirements (ETm) for different development stages after transplanting is, for the initial stage 0.4-0.6 (15 to 20 days), the crop development stage 0.7-0.8 (25 to 35 days), the mid-season stage 0.95-1. 1 (25 to 45 days), the late-season stage 0.85-0.9 (35 to 45 days), and at harvest 0. 75-0.85.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

Onion, in common with most vegetable crops, is sensitive to water deficit. For high yield, soil water depletion should not exceed 25 percent of available soil water. When the soil is kept relatively wet, root growth is reduced and this favours bulb enlargement. Irrigation should be discontinued as the crop approaches maturity to allow the tops to desiccate, and also to prevent a second flush of root growth.

The growth periods of an onion crop with a growing period of 100 to 140 days in the field are: establishment period (from sowing to transplanting, 0) 30 to 35 days; vegetative period (1) 25 to 30 days; yield formation (bulb enlargement, 3) 50 to 80 days; and ripening period (4) 25 to 30 days.

The crop is most sensitive to water deficit during the yield formation period (3), particularly during the period of rapid bulb growth which occurs about 60 days after transplanting. - The crop is equally sensitive during transplantation. For a seed crop, the flowering period is very sensitive to water deficit. During the vegetative growth period (1) the crop appears to be relatively less sensitive to water deficits.

For high yield of good quality the crop needs a controlled and frequent supply of water throughout the total growing period; however, over-irrigation leads to reduced growth.

To achieve large bulb size and high bulb weight, water deficits, especially during the yield formation period (bulb enlargement, 3), should be avoided. Under limited water supply small water savings can be made during the vegetative period (1) and the ripening period (4). However, under such conditions water supply should preferably be directed toward maximizing production per hectare rather than extending the cultivated area with limited water supply.The crop has a shallow root system with roots concentrated in the upper 0.3m soil depth. In general 100 percent of the water uptake occurs in the first 0.3 to 0.5rn soil depth (D = 0.3-0. 5 m). To meet full crop water requirements (ETm) the soil should be kept relatively moist; under an evapotranspiration rate of 5 to 6 mm/day, the rate of water uptake starts to reduce when about 25 percent of the total available soil water has been depleted (p = 0.25).The crop requires frequent, light irrigations which are timed when about 25 percent of available water in the first 0.3 m soil depth has been depleted by the crop. Irrigation application every 2 to 4 days is commonly practised. Over-irrigation some-times causes spreading of diseases such as mildew and white rot. Irrigation can be discontinued 15 to 25 days before harvest. Most common irrigation methods are furrow and basin.Frequent irrigation is required to prevent cracking of the bulb and forming of 'doubles'. Also adequate water supply is essential for a high quality crop. A good bulb yield under irrigation is 35 to 45 ton/ha. The water utilization efficiency for harvested yield (Ey) for bulbs containing 85 to 90 percent moisture is 8 to 10 kg/m3. � � � � � � � � � � � � � � � � � � � ��� � This section presents information on water relations and water management of pepper and provides links to other sources of information.Pepper (Capsicum annum�and�Capsicum frutescens) is thought to originate from tropical America. Most of the peppers grown belong to C. annum but the small, pungent peppers belong to C. frutescens. Present world production is about 19 million tons fresh fruit from 1.5 million ha.(FAOSTAT, 2001).

Pepper thrives in climates with growing season temperatures in the range of 18 to 27�C during the day and 15 to 18� C during the night. Lower night temperatures result in greater branching and more flowers; warmer night temperatures induce earlier flowering and this effect is more pronounced as light intensity increases.

The crop is grown extensively under rainfed conditions and high yields are obtained with rainfall of 600 to 1250 mm, well-distributed over the growing season. Heavy rainfall during the flowering period causes flower shedding and poor fruit setting, and during the ripening period rotting of fruits.

Light-textured soils with adequate water holding capacity and drainage are preferred. Optimum pH is 5.5 to 7.0 and acid soils require liming. Waterlogging, even for short periods, causes leaf shedding. Fertilizer requirements are 100 to 170 kg/ha N, 25 to 50 kg/ha P and 550 to 100 kg/ha K.

The crop is moderately sensitive to soil salinity, except in the seedling stage when it is more sensitive. Yield decrease at different levels of ECe is: 0% at ECe 1.5 mmhos/cm, 10% at 2.2, 25% at 3.3, 50% at 5.1 and 100% at ECe 8.5 mmhos/cm.

Seeds are sown in nursery beds which in the cooler climates are sometimes enclosed and heated since soil temperatures in the range of 20 to 24�C are considered optimum for germination. Seedlings of 10 to 20 cm height are transplanted in the field after 25 to 35 days. The length of the total growing period varies with climate and variety but in general it takes 120 to 150 days from sowing to the latest harvest. Prior to transplanting, the seedlings raised in enclosed and heated nurseries are hardened by increased ventilation. The plants are sometimes topped 10 days before transplanting to encourage branching. Plant spacing is 0.4 to 0.6 m x 0.9 m. For production of fruits for canning, closer spacings are sometimes used. Flowering starts 1 to 2 months after transplanting with first picking of green peppers 1 month later. Thereafter, ripe, red peppers are picked at 1 to 2 week intervals for up to 3 months. Ripe chillies are semi-dried for 3 to 15 days, with the final weight being about 25 percent of the fresh fruit weight.

The graph below depicts the crop stages of pepper, and the table summarises the main crop coefficients used for water management.Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days�25/303035404011020301252l0Apr/JunOct.Europe and Medit.�Arid RegionDepletion Coefficient, p:0.2>>0.30.50.3Root Depth, m0.25>>-0.8-Crop Coefficient,Kc0.6>>1.050.9-�Yield Response Factor, Ky----1.1��Total water requirements (ETm) are 600 to 900 mm and up to 1250 mm for long growing periods and several pickings. The crop coefficient (kc) relating reference evapotranspiration (ETo) to maximum evapotranspiration (ETm) is 0.4 following transplanting, 0.95 to 1. 1 during full cover and for fresh peppers 0.8 to 0.9 at time of harvest.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of root yield are shown in the figure below.The relationships between relative yield decrease (1 - Ya/Ym) and soil water depletion for pepper are shown in the figure below.

For high yields, an adequate water supply and relatively moist soils are required during the total growing period. Reduction in water supply during the growing period in general has an adverse effect on yield and the greatest reduction in yield occurs when there is a continuous water shortage until the time of first picking. The period at the beginning of the flowering period is most sensitive to water shortage and soil water depletion in the root zone during this period should not exceed 25 per-cent. Water shortage just prior and during early flowering reduces the number of fruits. The effect of water deficit on yield during this period is greater under conditions of high temperature and low humidity. Controlled irrigation is essential for high yields because the crop is sensitive to both over and under irrigation.

With poor quality (saline) water the yield of first pickings is reduced but the effect is less pronounced on later pickings. Sprinkling with poor quality (saline) water causes leaf burn and 'nose rot' of the fruits. Water deficits during yield formation period lead to shrivelled and malformed fruits. The pungent quality of the fruit (hotness) can to a certain degree be influenced by water supply.

Under conditions of limited water supply, total production is increased by meeting full crop water requirements over a limited area, rather than by extending the area and partially meeting the crop water requirements.Pepper has a tap root which is broken at the time of transplanting and a profusely branched lateral root system subsequently develops. Root depth can extend up to 1 m but under irrigation roots are concentrated mainly in the upper 0.3m soil depth. Normally 100 percent of the water uptake occurs in the first 0.5 to 1.0 m soil depth (D = 0.5-1.0 m). Under conditions when maximum evapotranspiration is 5 to 6 mm/day, 25 to 30 percent of the total available soil water can be depleted until soil water uptake wi 11 be reduced (p=0.25 to 0.30).For optimum yield levels the soil water depletion in most climates should not exceed 30 to 40 percent of the total available soil water. Due to the low depletion level light irrigation applications are required. Irrigation frequencies of 4 to 7 days are common. When water supply is short, irrigation should preferably be adequate up to the first picking and savings may be made thereafter.Peppers are grown under surface, sprinkler and drip irrigation. With sprinkler irrigation, yields tend to be higher under light applications as compared to heavy intensity sprinkling. However, with poor quality water, heavy intensity and large amounts are generally preferred with sprinkler irrigation because of reduced leaf burning and improved leaching of salts. The crop is particularly suitable for drip irrigation where very high yields can be obtained.Yields vary greatly with climate and length of growing period, e.g. number of pickings. Under irrigation commercial yields are in the range of 10 to 15 ton/ha fresh fruit and 20 to 25 ton/ha are obtained under favourable climatic conditions. However, the marketable yield percentage may vary. Number of pickings is 1 for machine harvesting and up to 6 for hand picking, depending on the length of the harvesting period. The water utilization efficiency for harvested yield (Ey) for fresh pepper containing about 90 percent moisture varies between 1.5 and 3.0 kg/m3 � � � � � � � � � � � � � � � � � � � ��� � This section presents information on water relations and water management of tomato and provides links to other sources of information.Tomato (Lycopersicon esculentum) is the second most important vegetable crop next to potato. Present world production is about 100 million tons fresh fruit from 3.7 million ha.(FAOSTAT, 2001).

Tomato is a rapidly growing crop with a growing period of 90 to 150 days. It is a daylength neutral plant. Optimum mean daily temperature for growth is 18 to 25�C with night temperatures between 10 and 20�C. Larger differences between day and night temperatures, however, adversely affect yield. The crop is very sensitive to frost. Temperatures above 25�C, when accompanied by high humidity and strong wind, result in reduced yield. Night temperatures above 2O�C accompanied by high humidity and low sunshine lead to excessive vegetative growth and poor fruit production. High humidity leads to a greater incidence of pests and diseases and fruit rotting. Dry climates are therefore preferred for tomato production.

Tomato can be grown on a wide range of soils but a well-drained, light loam soil with pH of 5 to 7 is preferred. Waterlogging increases the incidence of diseases such as bacterial wilt. The fertilizer requirements amount, for high producing varieties, to 100 to 150 kg/ha N, 65 to 110 kg/ha P and 160 to 240 kg/ha K.

The seed is generally sown in nursery plots and emergence is within 10 days. Seedlings are transplanted in the field after 25 to 35 days. In the nursery the row distance is about 10 cm. In the field spacing ranges from 0.3/0.6 x 0.6/1 m with a population of about 40,000 plants per ha. The crop should be grown in a rotation with crops such as maize, cabbage, cowpea, to reduce pests and disease infestations.

The crop is moderately sensitive to soil salinity. Yield decrease at various ECe values is: 0% at ECe 2.5 mmhos/cm, 10% at 3.5, 25% at 5.0, 50% at 7.6 and 100'/. at ECe 12.5 mmhos/cm. The most sensitive period to salinity is during germination and early plant development, and necessary leaching of salts is therefore frequently practised during pre-irrigation or by over-watering during the initial irrigation application.

The graph below depicts the crop stages of tomato, and the table summarises the main crop coefficients used for water management.Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days�3035253530404040454040506070452530303030135155155180145JanApr/MayJanOct/NovApr/MayArid RegionCalif., USACalif., Desert�USAArid RegionMediterraneanDepletion Coefficient, p:0.3>>0.40.50.3Root Depth, m0.25>>-1.0-Crop Coefficient,Kc0.6>>1.150.7-0.9-�Yield Response�Factor, Ky0.41.10.80.41.05��Total water requirements (ETm) after transplanting, of a tomato crop grown in the field for 90 to 120 days, are 400 to 600 mm, depending on the climate. Water requirements related to reference evapotranspiration (ETo) in mm/period are given by the crop factor (Kc) for different crop development stages, or: during the initial stage 0. 4-0. 5 (10 to 15 days), the development stage 0. 7-0.8 (20 to 30 days), the mid- season stage 1.05-1.25 (30 to 40 days), the late-season stage 0.8-0.9 (30 to 40 days) and at harvest 0.6-0.65.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period are shown in the figure below.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growing periods are shown in the figure below.

The plant produces flowers from bottom to top during the active development of the stem. Fruits can be harvested while the plant is still flowering at the top. Some-times three flowering periods related to three harvests can be distinguished. However, for mechanical harvesting where the fruits are used for tomato paste, only one picking is made. Water supply needs to be adjusted according to the use of the product, c. g. for salad or paste.

Highest yields of salad tomatoes are obtained by frequent, light irrigation. Where mechanical harvesting is used, heavy, infrequent irrigation is more appropriate with the last irrigation applied long before harvest.

Following table presents the growth periods of tomato at the first harvestStageDevelopment StageStage length, days0Establishment25-351Vegetative20-252Flowering20-303Yield formation20-304Ripening15-20Total100-140 days���For subsequent harvest periods, 2, 3 and 4 will overlap and an additional 20 to 30 days are required for each harvest.

The relationship between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit (1 - ETa/ETm) is given in the following figure. The crop is most sensitive to water deficit during and immediately after transplanting and during, flowering (2) and yield formation (3). Water deficit during the flowering period (2) causes flower drop. Moderate water deficit during the vegetative period (1) enhances root growth.

For high yield and good quality, the crop needs a controlled supply of water throughout the growing period. Whereas under water limiting conditions some water savings may be made during the vegetative (1) and ripening (4) periods, water supply should preferably be directed toward maximizing production per ha rattler than extending the cultivated area under limited water supply.The crop has a fairly deep root system and in deep soils roots penetrate up to some 1. 5 m. The maximum rooting depth is reached about 60 days after transplanting. Over 80 percent of the total water uptake occurs in the first 0.5 to 0.7 m and 100 percent of the water uptake of a full grown crop occurs from the first 0.7 to 1.5 m (D = 0.7 - 1.5 m). Under conditions when maximum evapotranspiration (ETm) is 5 to 6 mm/ day water uptake to meet full crop water requirements is affected when more than 40 percent of the total available soil water has been depleted (p = 0.4).The crop performance is sensitive to the irrigation practices. In general a prolonged severe water deficit limits growth and reduces yields which cannot be corrected by heavy watering later on. Highest demand for water is during flowering. however, withholding irrigation during this period is sometimes recommended to force less mature plants into flowering in order to obtain uniform flowering and ripening. Care should be exercised in this to avoid damage to the mature plants.

Excessive watering during the flowering period (2) has been shown to increase flower drop and reduce fruit set. Also this may cause excessive vegetative growth and a delay in ripening. Water supply during and after fruit set must be limited to a rate which will prevent stimulation of new growth at the expense of fruit development. Heavy, irregular irrigations or dry periods alternating with wet periods should be avoided. For production of salad tomato with more than one harvest, the crop flourishes best under light, frequent irrigation, well-distributed over the growing period with the soil depletion level during the different growth periods remaining below 40 percent ($p < 0.4$). This promotes optimum growth during the total growing period and results in high yield of good quality. With one harvest uniform ripening is required and the depletion level during this period may increase to 60 to 70 percent.

When water supply is limited, application for a salad crop can be concentrated during periods of transplanting, flowering (2) and yield formation (3). For a crop grown for paste production, a more extensive irrigation may be applied with last heavy irrigation applied prior to flowering.Surface irrigation by furrow is commonly practised. Under sprinkler irrigation the occurrence of fungal diseases and possibly bacterial canker may become a major problem. Further, under sprinkler, fruit set may be reduced with an increase in fruit rotting. In the case of poor quality water, leaf burn will occur with sprinkler irriga-tion; this may be reduced by sprinkling at night and shifting of sprinkler lines with the direction of the prevailing wind. Due to the crops specific demands for a high soil water content achieved without leaf wetting, trickle or drip irrigation has been successfully applied.Frequent light irrigation improve the size, shape, juiciness and colour of the fruit, but total solids (dry matter content) and acid content will be reduced. However, the decrease in solids will lower the fruit quality for processing. In selecting the irrigation practices consideration must therefore be given to teh type of end product required. Prolonged water deficits leads to fruit cracking. Where fruit rot is a problem, frequent sprinkler irrigation should be avoided during the period of yield formation.

A good commercial yield under irrigation is 45 to 65 tons/ha fresh fruit, of which 80 to 90 percent is moisture, depending on the use of the product. the water utilization efficiency for harvested yield (Ey) for fresh tomatoes is 10 to 12 kg/m3 � � � � � � � � � � � � � � � � � � � � ��� � This section presents information on water relations and water management of watermelon and provides links to other sources of information.Watermelon (Citrullus vulgaris) is native to the dry areas in tropical and sub-tropical Africa south of the equator. The crop can survive the desert climate when groundwater is available and the fruit sometimes serves as a source of water for human consumption. World production is about 77.5 million tons fruit from 3.1 million ha.(FAOSTAT, 2001).

The crop prefers a hot, dry climate with mean daily temperatures of 22 to 30�C. Maximum and minimum temperatures for growth are about 35 and 18�C respectively. The optimum soil temperature for root growth is in the range of 20 to 35�C. Fruits grown under hot, dry conditions have a high sugar content of 11 percent in comparison to 8 percent under cool, humid conditions. The crop is very sensitive to frost. The length of the total growing period ranges from 80 to 110 days, depending on climate.

The crop prefers a sandy loam soil texture with pH of 5.8 to 7.2. Cultivation in heavy textured soils results in a slower crop development and cracked fruits. For high production fertilizer requirements are 80 to 100 kg/ha N, 25 to 60 kg/ha P and 35 to 80 kg/ha K.

The crop is moderately sensitive to salinity. Yield decrease due to salinity appears to be similar to that of cucumber, or: 0% at ECe 2.5 mmhos/cm, 10% at 3.3, 25% at 4.4, 50% at 6.3 and 100% at ECe 10 mmho s / cm .

Watermelon is normally seeded directly in the fields. Thinning is practised 15 to 25 days after sowing. Spacing between plants and rows varies from 0.6 x 0.9 to 1.8 x 2.4 m. Seeds are sometimes placed on hills spaced 1.8 x 2.4m. In areas prone to frost, sowing time is dictated often by the occurrence of frost; sometimes black plastic mulch is used for frost protection.

The graph below depicts the crop stages of watermelon, and the table summarises the main crop coefficients used for water management.Stages of�DevelopmentPlantdateRegionCropcharacteristicInitialCropDevelopmentMid-seasonLateTotal�Stage length,�days�2010302030203030110 80AprMar/AugItalyNear East (desert)Depletion Coefficient, p----0.4Root Depth, m----0.8Crop Coefficient,Kc0.4>>1.00.75-�Yield Response�Factor, Ky0.450.80.80.31.1��Under conditions of high evaporation, irrigation intervals may be as short as 6 to 8 days. For maximum production the crop coefficients (kc) relating water requirements (ETm) to reference evapotranspiration (ETo) are: during the 10 to 20 day initial stage, 0.4-0.5, during the 15 to 20 days development stage, 0.7-0.8; the 35 to 50 day mid-season stage 0.95-1.05; and the 10 to 15 day late-season stage, 0.8-0.9. After 70 to 105 days, at harvest, kc is 0.65-0. 75. Water requirements for the total growing period for a 100-day crop range from 400 to 600 mm.The relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the total growing period of watermelon are shown in the figure below.

This figure shows the relationships between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth periods.

� The crop can deplete soil water to a soil water tension of over 2 atmospheres without the yield being affected. Irrigation should take place when, depending on the level of evaporation, the soil water has been depleted some 50 to 70 percent of available soil water. In dry climates with moderate evaporation and little rain the watermelon produces an acceptable yield (15 ton/ha) with one heavy irrigation in the beginning of the growing period when soil water over the full root depth is brought to field capacity.

The growth periods of a 80 to 110 day watermelon are: the establishment period (0) of 10 to 15 days; the vegetative period (1) of 20 to 25 days, including early (1a) and late vegetative growth (vine development, 1b); the flowering period of 15 to 20 days; yield formation (fruit filling, 3) of 20 to 30 days and ripening (4) 15 to 20 days. The crop usually has 4 fruits per plant, which is controlled by pruning practices, and harvest date depends on the number of fruits per plant and on uniformity of ripening.

The relationship between relative yield decrease and relative evapotranspiration deficit is given in Figure 50. Water deficit during the establishment period (0) delays growth and produces a less vigorous plant. When water deficit occurs during the early vegetative period (1a), less leaf area is produced which causes yield reduction. The late vegetative period (vine development, 1b), the flowering period (2) and the yield formation period (fruit filling, 3) are the most sensitive periods to water deficit. During the ripening period (4) a reduced water supply improves fruit quality. Yields are little affected by water deficits immediately prior to harvest.

Whereas under limiting conditions some water savings may be made during vegetative (1) and ripening (4) periods, water supply should be directed toward maximizing production per ha by meeting full crop water requirements rather than extending the cultivated area under limited supply.Water uptake varies with soil type and irrigation practices. The root system can be deep and extensive up to a depth of 1.5 to 2m. The active root zone where most of the water is abstracted under adequate water supply is limited to the first 1.0 to 1.5 (D = 1.0-1.5m). Under moderate evapotranspiration (ETm is 5 to 6mm/day), the crop can deplete the available soil water up to 40 or 50 percent before ETm is affected (p = 0.4-0.5).Where evaporation is high and rainfall is low, frequent irrigation with an interval from 7 to 10 days may be necessary. Irrigation under dry conditions must be scheduled at the start of the growing period (pre-irrigation), during the late vegetative period (vine development, 1b), the flowering period (2) and the yield formation period (3). In these periods soil water depletion must not exceed 50 percent. During the ripening period (4) relatively dry soils are preferred to increase sugar content and to avoid the flesh becoming more fibrous and less juicy.

Under moderate evaporation and deep soil with some rain during the growing season, one heavy irrigation may be sufficient to bring the crop to maturity.The most common method is by furrow. Under conditions where crop water requirements are high and the soils are light textured, drip irrigation has been successfully applied with a reduction in overall water demands. The crop has been grown successfully under spate or flood irrigation on basins with one application of 250 to 350 mm and little or no rainfall and with farmers' yields of about 12 ton/ha with a maximum of 20 ton/ha.Within certain water deficit limits, irrigation practices do not greatly affect the number of fruits per plant but affect the fruit size, shape, weight and quality. Ample water supply during the ripening period (4) reduces the sugar content and adversely affects the flavour. Severe water deficit in the ripening period on the other hand causes cracked and irregularly-shaped fruits.

A good commercial yield under irrigation is 25 to 35ton/ha. The water utilization efficiency for harvested yield (Ey) for fresh fruits containing about 90 percent moisture varies between 5 and 8kg/m3 � �
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3Live components

Toggle Live components subsection

3.1Plants

3.2Fish (or other aquatic creatures)

3.3Bacteria

3.1Plants

3.2Fish (or other aquatic creatures)

3.3Bacteria

4Hydroponic subsystem

5Biofilter

6Operation

Toggle Operation subsection

6.1Feed source

6.2Plant nutrients

6.3Water usage

6.4Energy usage

6.5Fish stocking

6.6Disease and pest management

6.7Automation, monitoring, and control

6.8Economic viability

6.1Feed source

6.2Plant nutrients

6.3Water usage

6.4Energy usage

6.5Fish stocking

6.6Disease and pest management

6.7Automation, monitoring, and control

6.8Economic viability

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cattle

pigs

poultry

sheepcattlepigspoultrysheepDairyDrylandExtensiveFertilizerFree-rangeGrazing

Convertible husbandry

Rotational grazingConvertible husbandryRotational grazingHobbyIntensive

animals

pigs

cropsanimalspigscropsNaturalMonocultureOrchardOrganicPaddy fieldRanchingSharecroppingSlash-and-burnSmallholdingTerraceSteam sterilizationAquacultureAquaponicsHydroponicsAeroponicsAgribusinessAgricultural engineeringAgricultural machineryAgricultural machinery industryAgricultural scienceAgricultural technologyAgroecologyAgroforestryAgronomyAnimal-freeCrop diversityDigitalEcologyLivestockMechanisationPermacultureSustainableUrbanAgriculturist professionAgricultural machineryGovernment ministriesUniversities and collegesAgriculture

by country

companiesby countrycompaniesBiotechnologyLivestockMeat industryPoultry farmingvteAztec cultivated agricultural islands known as chinampas in a system considered by some to be an early form of aquaponics for agricultural use,[4][5] where plants were raised on stationary (or sometime movable) islands in lake shallows and waste materials dredged from the Chinampa canals and surrounding cities were used to manually irrigate the plants.[4][6]South China and the whole of Southeast Asia, where rice was cultivated and farmed in paddy fields in combination with fish, are cited as examples of early aquaponics systems, although the technology had been brought by Chinese settlers who had migrated from Yunnan around 5 AD.[7] These polycultural farming systems existed in many Far Eastern countries and raised fish such as the oriental loach (泥鳅, ドジョウ),[8] swamp eel (黄鳝, 田鰻), common carp (鯉魚, コイ) and crucian carp (**鯽魚**)[9] as well as pond snails (田螺) in the paddies.[10][11]The 13th century Chinese agricultural manual Wang Zhen's Book on Farming (王禎農書) described floating wooden rafts which were piled with mud and dirt and which were used for growing rice, wild rice, and fodder. Such floating planters were employed in regions constituting the modern provinces of Jiangsu, Zhejiang, and Fujian. These floating planters are known as either jiatian (架田) or fengtian (葑田), which translates to "framed paddy" and "brassica paddy", respectively. The agricultural work also references earlier Chinese texts, which indicated that floating raft rice cultivation was being used as early as the Tang Dynasty (6th century) and Northern Song Dynasty (8th century) periods of Chinese history.[12]Rearing tank: the tanks for raising and feeding the fish;Settling basin: a unit for catching uneaten food and detached biofilms, and for settling out fine particulates;Biofilter: a place where the nitrification bacteria can grow and convert ammonia into nitrates, which are usable by the plants;[18]Hydroponics subsystem: the portion of the system where plants are grown by absorbing excess nutrients from the water;Sump: the lowest point in the system where the water flows to and from which it is pumped back to the rearing tanks.Deep-water raft aquaponics: styrofoam rafts floating in a relatively deep aquaculture basin in troughs. Raft tanks can be constructed to be quite large, and enable seedlings to be transplanted at one end of the tank while fully grown plants are harvested at the other, thus ensuring optimal floor space usage.[26]Recirculating aquaponics: solid media such as gravel or clay beads, held in a container that is flooded with water from the aquaculture. This type of aquaponics is also known as closed-loop aquaponics.[citation needed]Reciprocating aquaponics: solid media in a container that is alternately flooded and drained utilizing different types of siphon drains. This type of aquaponics is also known as flood-and-drain aquaponics or ebb-and-flow aquaponics.[citation needed]Nutrient film technique channels: plants are grown in lengthy narrow channels, with a film of nutrient-filled water constantly flowing past the plant roots. Due to the small amount of water and narrow channels, helpful bacteria cannot live there and therefore a bio filter is required for this method.[26]Other systems use towers that are trickle-fed from the top, horizontal PVC pipes with holes for the pots, plastic barrels cut in half with gravel or rafts in them. Each approach has its own benefits.[27]Use a feeding rate ratio for design calculationsKeep feed input relatively constantSupplement with calcium, potassium and ironEnsure good aerationRemove solidsBe careful with aggregatesOversize pipesUse biological pest controlEnsure adequate biofiltrationControl pHSequential rearing: Multiple age groups of fish share a rearing tank, and when an age group reaches market size they are selectively harvested and replaced with the same amount of fingerlings.[18] Downsides to this method include stressing out the entire pool of fish during each harvest, missing fish resulting in a waste of food/space, and the difficulty of keeping accurate records with frequent harvests.[18]Stock splitting: Large quantities of fingerlings are stocked at once and then split into two groups once the tank hits maximum capacity, which is easier to record and eliminates fish being "forgotten". A stress-free way of doing this operation is via "swimways" that connect various rearing tanks and a series of hatches/moving screens/pumps that move the fish around.[18]Multiple rearing units: Entire groups of fish are moved to larger rearing tanks once their current tank hits maximum capacity. Such systems usually have 2-4 tanks that share a filtration system, and when the largest tank is harvested, the other fish groups are each moved up into a bigger tank whilst the smallest tank is restocked with fingerlings.[18] It is also common for there to be several rearing tanks yet no ways to move fish between them, which eliminates the labor of moving fish and allows each tank to be undisturbed during harvesting, even if the space usage is inefficient when the fish are fingerlings.[18]Europe

The Urban Farming Company,[50] an organization based out of Switzerland, has been created to offer a method of rooftop based aquaponic growing systems to businesses. Its purpose is to offer fresh, sustainable produce to local urban areas.

In March 2018 the European Aquaponics Association[51] was established among European countries. This opened up an organization for European countries to continue aquaponic research and the implementation of aquaponic practices.

EcoPonics[52] is an aquaponics company based out of Iceland that is joining similar companies from Iceland, Denmark, and Spain to advocate for the implementation of commercial and competitive Aquaponics systems in European countries.

The Caribbean island of Barbados created an initiative to start aquaponics systems at home, called the aquaponic machine, with revenue generated by selling produce to tourists in an effort to reduce growing dependence on imported food.[citation needed] Vegetable production part of the low-cost Backyard Aquaponics System developed at Bangladesh Agricultural UniversityThe Urban Farming Company,[50] an organization based out of Switzerland, has been created to offer a method of rooftop based aquaponic growing systems to businesses. Its purpose is to offer fresh, sustainable produce to local urban areas.In March 2018 the European Aquaponics Association[51] was established among European countries. This opened up an organization for European countries to continue aquaponic research and the implementation of aquaponic practices.EcoPonics[52] is an aquaponics company based out of Iceland that is joining similar companies from Iceland, Denmark, and Spain to advocate for the implementation of commercial and competitive Aquaponics systems in European countries.The Caribbean island of Barbados created an initiative to start aquaponics systems at home, called the aquaponic machine, with revenue generated by selling produce to tourists in an effort to reduce growing dependence on imported food.[citation needed] Vegetable production part of the low-cost Backyard Aquaponics System developed at Bangladesh Agricultural UniversityAsia

In Bangladesh, the world's most densely populated country, most farmers use agrochemicals to enhance food production and storage life, though the country lacks oversight on safe levels of chemicals in foods for human consumption.[53] To combat this issue, a team led by M.A. Salam at the Department of Aquaculture of Bangladesh Agricultural University has created plans for a low-cost aquaponics system to provide organic produce and fish for people living in adverse climatic conditions such as the salinity-prone southern area and the flood-prone haor area in the eastern region.[54][55] Salam's work innovates a form of subsistence farming for micro-production goals at the community and personal levels whereas design work by Chowdhury and Graff was aimed exclusively at the commercial level, the latter of the two approaches take advantage of economies of scale.

An aquaponic gardening system is developed for use on rooftops in Gaza City.[56]

In Malaysia Alor Gajah, Melaka, Organization 'Persatuan Akuakutur Malaysia' takes innovative approach in aquaponics by growing Lobster in aquaponics.[citation needed]

Aquaponics in India aims to provide aspiring farmers with aquaponics solutions for commercial and backyard operation.[57]In Bangladesh, the world's most densely populated country, most farmers use agrochemicals to enhance food production and storage life, though the country lacks oversight on safe levels of chemicals in foods for human consumption.[53] To combat this issue, a team led by M.A. Salam at the Department of Aquaculture of Bangladesh Agricultural University has created plans for a low-cost aquaponics system to provide organic produce and fish for people living in adverse climatic conditions such as the salinity-prone southern area and the flood-prone haor area in the eastern region.[54][55] Salam's work innovates a form of subsistence farming for micro-production goals at the community and personal levels whereas design work by Chowdhury and Graff was aimed exclusively at the commercial level, the latter of the two approaches take advantage of economies of scale.An aquaponic gardening system is developed for use on rooftops in Gaza City.[56]In Malaysia Alor Gajah, Melaka, Organization 'Persatuan Akuakutur Malaysia' takes innovative approach in aquaponics by growing Lobster in aquaponics.[citation needed]Aquaponics in India aims to provide aspiring farmers with aquaponics solutions for commercial and backyard operation.[57]North America

Dakota College at Bottineau in Bottineau, North Dakota has an aquaponics program that gives students the ability to obtain a certificate or an AAS degree in aquaponics.[58]

The Smith Road facility in Denver started pilot program of aquaponics to feed 800 to 1,000 inmates at the Denver Jail, and a neighboring downtown facility which consists of 1,500 inmates and 700 officers.[59]

VertiFarms in New Orleans targets corporate rooftops for vertical farming, accruing up to 90 corporate clients for rooftop vertical farming in 2013.[60]

Windy Drumlins Farm in Wisconsin redesigns aquaponic-solar greenhouse for extreme weather conditions which can endure extremely cold climate.[61]

Volunteer operation in Nicaragua "Amigos for Christ" manages its plantation for feeding 900+ poverty-stricken school children by using nutrients from aquaponic methods.[61]

Verticulture in Bedstuy utilizes old Pfizer manufacturing plant for producing basil in commercial scale through aquaponics, yielding 30-40 pounds of basil a week.[62]

Upward Farms in New York expands to full-scale commercial facility, which will generate 130,000 pounds of greens and 50,000 pounds of fish a year.[63]

There has been a shift towards community integration of aquaponics, such as the nonprofit foundation Growing Power that offers Milwaukee youth job opportunities and training while growing food for their community. The model has spawned several satellite projects in other cities, such as New Orleans where the Vietnamese fisherman community has suffered from the Deepwater Horizon oil spill, and in the South Bronx in New York City.[64]

Whispering Roots is a non-profit organization in Omaha, Nebraska that provides fresh, locally grown, healthy food for socially and economically disadvantaged communities by using aquaponics, hydroponics and urban farming.[65][66]

Recently, aquaponics has been moving towards indoor production systems. In cities like Chicago, entrepreneurs are utilizing vertical designs to grow food year round. These systems can be used to grow food year round with minimal to no waste.[67]Dakota College at Bottineau in Bottineau, North Dakota has an aquaponics program that gives students the ability to obtain a certificate or an AAS degree in aquaponics.[58]The Smith Road facility in Denver started pilot program of aquaponics to feed 800 to 1,000 inmates at the Denver Jail, and a neighboring downtown facility which consists of 1,500 inmates and 700 officers.[59]VertiFarms in New Orleans targets corporate rooftops for vertical farming, accruing up to 90 corporate clients for rooftop vertical farming in 2013.[60]Windy Drumlins Farm in Wisconsin redesigns aquaponic-solar greenhouse for extreme weather conditions which can endure extremely cold climate.[61]Volunteer operation in Nicaragua "Amigos for Christ" manages its plantation for feeding 900+ poverty-stricken school children by using nutrients from aquaponic methods.[61]Verticulture in Bedstuy utilizes old Pfizer manufacturing plant for producing basil in commercial scale through aquaponics, yielding 30-40 pounds of basil a week.[62]Upward Farms in New York expands to full-scale commercial facility, which will generate 130,000 pounds of greens and 50,000 pounds of fish a year.[63]There has been a shift towards community integration of aquaponics, such as the nonprofit foundation Growing Power that offers Milwaukee youth job opportunities and training while growing food for their community. The model has spawned several satellite projects in other cities, such as New Orleans where the Vietnamese fisherman community has suffered from the Deepwater Horizon oil spill, and in the South Bronx in New York City.[64]Whispering Roots is a non-profit organization in Omaha, Nebraska that provides fresh, locally grown, healthy food for socially and economically disadvantaged communities by using aquaponics, hydroponics and urban farming.[65][66]Recently, aquaponics has been moving towards indoor production systems. In cities like Chicago, entrepreneurs are utilizing vertical designs to grow food year round. These systems can be used to grow food year round with minimal to no waste.[67]Caribbean

Fusion Farms in Mayagüez, Puerto Rico is the first hurricane-protected vertical farming operation using controlled environment aquaponics

(CEAq) that has been designated by the Government of Puerto Rico as a 'Company of Strategic Importance' due to the contribution they are making to help the island solve Food Security and Food sovereignty.Fusion Farms in Mayagüez, Puerto Rico is the first hurricane-protected vertical farming operation using controlled environment aquaponics (CEAq) that has been designated by the Government of Puerto Rico as a 'Company of Strategic Importance' due to the contribution they are making to help the island solve Food Security and Food sovereignty.Miscellaneous

In addition, aquaponic gardeners from all around the world are gathering in online community sites and forums to share their experiences and promote the development of this form of gardening[68] as well as creating extensive resources on how to build home systems.

There are various modular systems made for the public that utilize aquaponic systems to produce organic vegetables and herbs, and provide indoor decor at the same time.[69] These systems can serve as a source of herbs and vegetables indoors. Universities are promoting research on these modular systems as they get more popular among city dwellers.[70]In addition, aquaponic gardeners from all around the world are gathering in online community sites and forums to share their experiences and promote the development of this form of gardening[68] as well as creating extensive resources on how to build home systems.There are various modular systems made for the public that utilize aquaponic systems to produce organic vegetables and herbs, and provide indoor decor at the same time.[69] These systems can serve as a source of herbs and vegetables indoors. Universities are promoting research on these modular systems as they get more popular among city dwellers.[70]HydroponicsVertical farming^ Rakocy, James E. (2012-03-23), "Aquaponics-Integrating Fish and Plant Culture", Aquaculture Production Systems, Oxford, UK: Wiley-Blackwell, pp. 344–386, doi:10.1002/9781118250105.ch14, ISBN 978-1-118-25010-5, retrieved 2021-07-30

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passivepassiveAquatic gardenBottle gardenDeep water cultureKratky methodEbb and flowFogponicsMicroponicsNutrient film techniqueOrganic hydroponicsOrganopónicosSub-irrigated planterTop dripCharcoalCoco peatDiatomaceous earthExpanded clay aggregateGravelGrowstonesLava rockMineral woolPerlitePumiceRice hullsSandVermiculiteWood fibreGrow lightHydroponic dosersIrrigation sprinklerLeaf sensorNet-potSpray nozzleTimersUltrasonic hydroponic foggerWater chillerAlgacultureAquaculture of coralAquaculture of sea spongesControlled-environment agricultureHistorical hydrocultureHydroponicumPaludariumPlant nutritionPlant propagationRhizosphereRoot rotVertical farmingWater aeration Category Commons Wikibooks WikiversityCommercial fishingFish slaughterList of harvested aquatic animals by weightTrawlingPair trawlingMidwater trawlingBottom trawlingSeiningGillnettingLongliningTrollingDredgingFishing vesselsPower blockFish factoryFactory shipFish preservationSlurry iceDried fishFilleted fishGibbingSalmon cannerySalted fishSmoked fishKippersmore...SeafoodFish as foodCaviarCod liver oilFish roeFish emulsionFish mealFish hydrolysateFish oilFish protein powderFish sauceGravlaxHákarlLoxLutefiskRakfiskShrimp pasteSurimiSurströmmingSeafood listEdible seaweedsAlgaeCrustaceansMolluscsmore...Live fish tradeShrimp marketingChasse-maréeFishmongerFishwifeWorshipful Company of FishmongersBillingsgateFultonMaine AvenueEnglish MarketScaniaTsukijimore...World fish productionFishing by countryFishing banksOther areasAquaculture engineeringAquaponicsBest practicesCopper alloysFisheries and aquaculture research institutesGeothermal energy and aquacultureInland salineIntegrated multi-trophicMaricultureAntimicrobialsOffshoreOrganicRacewayRecirculatingBroodstockCatfishCobiaFish diseases and parasitesFish farmingFish feedFish hatcheryFish stockingSpawning bedSalmonTilapiaTailwaterUS hatcheriesGiant kelpMicroalgaeMicroalgal bacterial flocsPhotobioreactorRaceway pondSeaweedBrine shrimpCoralFreshwater prawnsGeoduckHirudicultureMarine shrimpOctopusOystersScallopsSea cucumberSea spongesTurtlesAustraliaCanadaChileChinaEast TimorFederated States of MicronesiaFijiIndonesiaKiribatiMadagascarMarshall IslandsNauruNew ZealandPalauPapua New GuineaSamoaSolomon IslandsSouth AfricaSouth KoreaTongaTuvaluUnited KingdomUnited States

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formal

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Charbagh

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As existing hydroponic and aquaculture farming techniques form the basis of all aquaponic systems, the size, complexity, and types of foods grown in an aquaponic system can vary as much as any system found in either distinct farming discipline.[3]

Aquaponics has ancient roots, although there is some debate on its first occurrence:

Floating aquaponics systems on polycultural fish ponds have been installed in China in more recent years on a large scale. They are used to grow rice, wheat and canna lily and other crops,[13] with some installations exceeding 2.5 acres (10,000 m2).[14]

The development of modern aquaponics is often attributed to the various works of the New Alchemy Institute and the works of Dr. Mark McMurtry et al. at the North Carolina State University, who devised an "Integrated Aqua-Vegeculture System" (iAVs) based on the combination of aquaculture and sand-based grow beds.[10]

Inspired by the successes of the New Alchemy Institute and McMurtry's iAVs, other institutes soon followed suit. Starting in 1979, Dr. James Rakocy and his colleagues at the University of the Virgin Islands researched and developed the use of deep water culture hydroponic grow beds in a large-scale aquaponics system.[15]

Other institutes focused their research on "ebb and flow" systems (also known as "flood and drain"), which were partially based on the original ideas developed at North Carolina State University, but where coarse media (such as gravel or expanded clay) replaced sand, while bell syphons allowed an ebb-and-flow irrigation cycle,[16] such systems are also known as "Speraneo Systems" because they are based on ideas developed in the 1990s by Tom and Paula Speraneo, owners of an aquaponics farm in Missouri.[17]

The first aquaponics research in Canada was a small system added onto existing aquaculture research at a research station in Lethbridge, Alberta. Canada saw a rise in aquaponics setups throughout the '90s, predominantly as commercial installations raising high-value crops such as trout and lettuce. A setup based on the deepwater system developed at the University of Virgin Islands was built in a greenhouse at Brooks, Alberta where Dr. Nick Savidov and colleagues researched aquaponics from a background of plant science. The team made findings on rapid root growth in aquaponics systems and on closing the solid-waste loop and found that, owing to certain advantages in the system over traditional aquaculture, the system can run well at a low pH level, which is favored by plants but not fish.[citation needed]

Aquaponics consists of two main parts, with the aquaculture part for raising aquatic animals and the hydroponics part for growing plants.[18][19] Aquatic effluents, resulting from uneaten feed or raising animals like fish, accumulate in water due to the closed-system recirculation of most aquaculture systems. The effluent-rich water becomes toxic to the aquatic animal in high concentrations but this contains nutrients essential for plant growth.[18] Although consisting primarily of these two parts, aquaponics systems are usually grouped into several components or subsystems responsible for the effective removal of solid wastes, for adding bases to neutralize acids, or for maintaining water oxygenation.[18] Typical components include:

Depending on the sophistication and cost of the aquaponics system, the units for solids removal, biofiltration, and/or the hydroponics subsystem may be combined into one unit or subsystem,[18] which prevents the water from flowing directly from the aquaculture part of the system to the hydroponics part. By utilizing gravel or sand as plant supporting medium, solids are captured and the medium has enough surface area for fixed-film nitrification.[18] The ability to combine biofiltration and hydroponics allows for aquaponic system, in many cases, to eliminate the need for an expensive, separate biofilter.[citation needed]

An aquaponic system depends on different live components to work successfully. The three main live components are plants, fish (or other aquatic creatures) and bacteria. Some systems also include additional live components like worms.

Many plants are suitable for aquaponic systems, though which ones work for a specific system depends on the maturity and stocking density of the fish. These factors influence the concentration of nutrients from the fish effluent and how much of those nutrients are made available to the plant roots via bacteria.

Green leaf vegetables with low to medium nutrient requirements are well adapted to aquaponic systems, including chinese cabbage, lettuce, basil, spinach, chives, herbs, and watercress.[19][20]Other plants, such as tomatoes, cucumbers, and peppers, have higher nutrient requirements and will do well only in mature aquaponic systems with high stocking densities of fish.[20]

Plants that are common in salads have some of the greatest success in aquaponics, including cucumbers, shallots, tomatoes, lettuce, capsicum, red salad onions and snow peas.[21]

Some profitable plants for aquaponic systems include chinese cabbage, lettuce, basil, roses, tomatoes, okra, cantaloupe and bell peppers.[19]

Other species of vegetables and/or fruit that grow well in an aquaponic system include watercress, basil, coriander, parsley, lemongrass, sage, beans, peas, kohlrabi, taro, Pomegranate, radishes, strawberries, melons, onions, turnips, parsnips, sweet potato, cauliflower, cabbage, broccoli, and eggplant as well as the choys that are used for stir fries.[21]

Freshwater fish are the most common aquatic animal raised using aquaponics due to their ability to tolerate crowding. Freshwater crayfish and prawns are also sometimes used,[22][18] as they excrete nutrient rich feces. There is a branch of aquaponics using saltwater fish, called saltwater aquaponics. There are many species of warmwater and cold-water fish that adapt well to aquaculture systems.

In practice, tilapia are the most popular fish for home and commercial projects that are intended to raise edible fish because it is a warmwater fish species that can tolerate crowding and changing water conditions.[20] Barramundi, silver perch, eel-tailed catfish or tandanus catfish, jade perch and Murray cod are also used.[19] For temperate climates when there isn't ability or desire to maintain water temperature, bluegill and catfish are suitable fish species for home systems.

Koi and goldfish may also be used, if the fish in the system need not be edible.

Other suitable fish include channel catfish, rainbow trout, perch, common carp, Arctic char, largemouth bass and striped bass.[20]

Nitrification, the aerobic conversion of ammonia into nitrates, is one of the most important functions in an aquaponic system as it reduces the toxicity of the water for fish, and allows the resulting nitrate compounds to be removed by the plants for nourishment.[18] Ammonia is steadily released into the water through the excreta and gills of fish as a product of their metabolism, but must be filtered out of the water since higher concentrations of ammonia (commonly between 0.5 and 1 ppm)[citation needed] can impair growth, cause widespread damage to tissues, decrease resistance to disease and even kill the fish.[23] Although plants can absorb ammonia from the water to some degree, nitrates are assimilated more easily,[19] thereby efficiently reducing the toxicity of the water for fish.[18] Ammonia can be converted into safer nitrogenous compounds through combined healthy populations of 2 types of bacteria: Nitrosomonas which convert ammonia into nitrites, and Nitrobacter which then convert nitrites into nitrates. While nitrite is still harmful to fish due to its ability to create methemoglobin, which cannot bind oxygen, by attaching to hemoglobin, nitrates are able to be tolerated at high levels by fish.[23]

For this, nitrite levels must be maintained at concentrations lower than 1ppm.[24] Nitrate, which is much safer for fish, can be tolerated at concentrations of over 150ppm.[25] Typically, nitrogen cycling (system cycling) must conducted for 3-5 weeks in order to achieve and maintain these ideal concentrations of nitrogen compounds. High surface area provides more space for the growth of nitrifying bacteria. Grow bed material choices require careful analysis of the surface area, price and maintainability considerations.

Plants are grown in hydroponics systems, with their roots immersed in the nutrient-rich effluent water. This enables them to filter out the ammonia that is toxic to the aquatic animals, or its metabolites. After the water has passed through the hydroponic subsystem, it is cleaned and oxygenated, and can return to the aquaculture vessels. This cycle is continuous. Common aquaponic applications of hydroponic systems include:

Since plants at different growth stages require different amounts of minerals and nutrients, plant harvesting is staggered with seedlings growing at the same time as mature plants. This ensures stable nutrient content in the water because of continuous symbiotic cleansing of toxins from the water.[28]

In an aquaponics system, the bacteria responsible for the conversion of ammonia to usable nitrates for plants form a biofilm on all solid surfaces throughout the system that are in constant contact with the water. The submerged roots of the vegetables combined have a large surface area where many bacteria can accumulate. Together with the concentrations of ammonia and nitrites in the water, the surface area determines the speed with which nitrification takes place. Care for these bacterial colonies is important as to regulate the full assimilation of ammonia and nitrite. This is why most aquaponics systems include a biofiltering unit, which helps facilitate growth of these microorganisms. Typically, after a system has stabilized ammonia levels range from 0.25 to .50 ppm; nitrite levels range from 0.0 to 0.25 ppm, and nitrate levels range from 5 to 150 ppm.[citation needed] During system startup, systems take several weeks to begin the nitrification process. [29] As a result, spikes may occur in the levels of ammonia (up to 6.0 ppm) and nitrite (up to 15 ppm) as the nitrosomonas and nitrobacter bacteria have yet to establish populations within the system. Nitrate levels peak later in the startup phase as the system completes nitrogen cycles and maintains a healthy biofilter and these bacteria grow into a mature colony.[30] with nitrate levels peaking later in the startup phase.[citation needed] In the nitrification process ammonia is oxidized into nitrite, which releases hydrogen ions into the water. Overtime the water's pH will slowly drop, non-sodium bases such as potassium hydroxide or calcium hydroxide can be used to neutralize the water's pH[18] if insufficient quantities are naturally present in the water to provide a buffer against acidification. In addition, selected minerals or nutrients such as iron can be added in addition to the fish waste that serves as the main source of nutrients to plants.[18]

A good way to deal with solids buildup in aquaponics is the use of worms, which liquefy the solid organic matter so that it can be utilized by the plants and/or other animals in the system. For a worm-only growing method, please see Vermiponics.[citation needed]

The five main inputs to the system are water, oxygen, light, feed given to the aquatic animals, and electricity to pump, filter, and oxygenate the water. Spawn or fry may be added to replace grown fish that are taken out from the system to retain a stable system. In terms of outputs, an aquaponics system may continually yield plants such as vegetables grown in hydroponics, and edible aquatic species raised in an aquaculture. Typical build ratios are .5 to 1 square foot of grow space for every 1 U.S. gal (3.8 L) of aquaculture water in the system. 1 U.S. gal (3.8 L) of water can support between .5 lb (0.23 kg) and 1 lb (0.45 kg) of fish stock depending on aeration and filtration.[31]

Ten primary guiding principles for creating successful aquaponics systems were issued by Dr. James Rakocy, the director of the aquaponics research team at the University of the Virgin Islands, based on extensive research done as part of the Agricultural Experiment Station aquaculture program.[32]

As in most aquaculture based systems, stock feed often consists of fish meal derived from lower-value species. Ongoing depletion of wild fish stocks makes this practice unsustainable. Organic fish feeds may prove to be a viable alternative that relieves this concern. Other alternatives include growing duckweed with an aquaponics system that feeds the same fish grown on the system,[33] excess worms grown from vermiculture composting, using prepared kitchen scraps,[34] as well as growing black soldier fly larvae to feed to the fish using composting grub growers.[35]

Like hydroponics, a few minerals and micronutrients can be added to improve plant growth. Iron is the most deficient nutrient in aquaponics, but it can be added through mixing Iron Chelate powder with water. Potassium can be added as potassium sulfate through foliar spray. Less vital nutrients include magnesium as epsom salt, calcium as calcium chloride, and boron.[36] Biological filtration of aquaculture wastes yield high nitrate concentrations, which is great for leafy greens. For flowering plants with high nutrient demands, it is recommended to introduce supplemental nutrients such as magnesium, calcium, potassium, and phosphorus. Common sources are sulfate of potash, potassium bicarbonate, monoammonium phosphate, etc. Nutrient deficiency in wastewater from fish component (RAS) can be completely masked using raw or mineralized sludge, usually containing 3–17 times higher nutrient concentrations. RAS effluents (wastewater and sludge combined) contain adequate N, P, Mg, Ca, S, Fe, Zn, Cu, Ni to meet most aquaponic crop needs. Potassium is generally deficient requiring full-fledged fertilization. Micronutrients B, Mo are partly sufficient and can be easily ameliorated by increasing sludge release. The presumption surrounding 'definite' phyto-toxic sodium levels in RAS effluents should be reconsidered – practical solutions available too. No threat of heavy metal accumulation exists within the aquaponics loop.[37]

Aquaponic systems do not typically discharge or exchange water under normal operation, but instead, recirculate and reuse water very effectively. The system relies on the relationship between the animals and the plants to maintain a stable aquatic environment that experience a minimum of fluctuation in ambient nutrient and oxygen levels. Plants are able to recover dissolved nutrients from the circulating water, meaning that less water is discharged and the water exchange rate can be minimized.[38] Water is added only to replace water loss from absorption and transpiration by plants, evaporation into the air from surface water, overflow from the system from rainfall, and removal of biomass such as settled solid wastes from the system. As a result, aquaponics uses approximately 2% of the water that a conventionally irrigated farm requires for the same vegetable production.[39] This allows for aquaponic production of both crops and fish in areas where water or fertile land is scarce. Aquaponic systems can also be used to replicate controlled wetland conditions. Constructed wetlands can be useful for biofiltration and treatment of typical household sewage.[40] The nutrient-filled overflow water can be accumulated in catchment tanks, and reused to accelerate growth of crops planted in soil, or it may be pumped back into the aquaponic system to top up the water level.[citation needed]

Aquaponic installations rely in varying degrees on man-made energy, technological solutions, and environmental control to achieve recirculation and water/ambient temperatures. However, if a system is designed with energy conservation in mind, using alternative energy and a reduced number of pumps by letting the water flow downwards as much as possible, it can be highly energy efficient. While careful design can minimize the risk, aquaponics systems can have multiple 'single points of failure' where problems such as an electrical failure or a pipe blockage can lead to a complete loss of fish stock.[citation needed]

In order for aquaponic systems to be financially successful and make a profit whilst also covering its operating expenses, the hydroponic plant components and fish rearing components need to almost constantly be at maximum production capacity.[18] To keep the bio-mass of fish in the system at its maximum (without limiting fish growth), there are three main stocking method that can help maintain this maximum.

Ideally the bio-mass of fish in the rearing tanks doesn't exceed 0.5 lbs/gallon, in order to reduce stress from crowding, efficiently feed the fish, and promote healthy growth.[18]

Although pesticides can normally be used to take care of insects on crops, in an aquaponic system the use of pesticides would threaten the fish ecosystem. On the other hand, if the fish acquire parasites or diseases, therapeutants cannot be used as the plants would absorb them.[18] In order to maintain the symbiotic relationship between the plants and the fish, non-chemical methods such as traps, physical barriers and biological control (such as parasitic wasps/ladybugs to control white flies/aphids) should be used to control pests.[18] The most effective organic pesticide is Neem oil, but only in small quantities to minimize spill over fish's water.[citation needed]. Commercialization of aquaponics is often stalled by bottlenecks in pest and disease management. The use of chemical control methods is highly complicated for all systems. While insecticides and herbicides are replaceable by well-established commercial biocontrol measures, fungicides and nematicides are still relevant in aquaponics. Monitoring and cultural control are the first approaches to contain pest population. Biological controls, in general, are adaptable to a larger extent. Non-chemical prophylactic measures are highly proficient for pest and disease prevention in all designs.[41]

Many have tried to create automatic control and monitoring systems and some of these demonstrated a level of success. For instance, researchers were able to introduce automation in a small scale aquaponic system to achieve a cost-effective and sustainable farming system.[42][43] Commercial development of automation technologies has also emerged. For instance, a company has developed a system capable of automating the repetitive tasks of farming and features a machine learning algorithm that can automatically detect and eliminate diseased or underdeveloped plants.[44] A 3.75-acre aquaponics facility that claims to be the first indoor salmon farm in the United States also includes an automated technology.[45] The aquaponic machine has made notable strides in the documenting and gathering of information regarding aquaponics.[citation needed]

Aquaponics offers a diverse and stable polyculture system that allows farmers to grow vegetables and raise fish at the same time. By having two sources of profit, farmers can continue to earn money even if the market for either fish or plants goes through a low cycle.[23] The flexibility of an aquaponic system allows it to grow a large variety of crops including ordinary vegetables, herbs, flowers and aquatic plants to cater to a broad spectrum of consumers.[23] Herbs, lettuce and speciality greens such as basil or spinach are especially well suited for aquaponic systems due to their low nutritional needs.[23] For the growing number of environmentally conscious consumers, products from aquaponic systems are organic and pesticide free, whilst also leaving a small environmental footprint.[23] Aquaponic systems additionally are economically efficient due to low water usage, effective nutrient cycling and needing little land to operate.[23] Because soil isn't needed and only a little bit of water is required, aquaponic systems can be set up in areas that have traditionally poor soil quality or contaminated water.[23] More importantly, aquaponic systems are usually free of weeds, pests and diseases that would affect soil, which allows them to consistently and quickly produce high quality crops to sell.[23]

The research pertaining to aquaponic systems, and their economic viability is still very limited compared to conventional hydroponic systems. With the research that is available, the economic viability of aquaponic businesses must be determined case by case. There are many variables including system design, seasonal weather, and local costs of energy or land that factor into the profitability of aquaponic businesses. According to a study that included 208 aquaponic businesses in the United States, the average investment cost of aquaponic businesses was $5,000 - $10,000 and only 10% of businesses were reporting more than $50,000 in annual revenue.[46]

There are two primary aquaponic systems: Single Recirculating Aquaponic Systems (SRAPS or coupled systems) and Double Recirculating Aquaponic Systems (DRAPS or decoupled systems). The primary difference is that in a DRAPS system, the water from the aquaculture (fish) system is used to provide nutrients to the hydroponic (plant) system but the two systems operate autonomously of each other. Unlike with SRAPS, a grower can add synthetic fertilizer into a DRAPS system without hurting the fish. DRAPS tomato systems that use fertilizers in addition to fish waste can provide the same level of production as conventional hydroponic systems while reducing fertilizer usage by 23.6%. SRAPS systems are not able to mimic these results.[47] Additional research shows the support that aquaponic systems can use 14% less fertilizer than hydroponic systems.[48] Despite this reduction, a grower should determine if the cost of maintaining aquaculture is cheaper than the use of extra fertilizer in hydroponics.

Other non-system-based barriers to the economic success of aquaponic systems could include that these systems require a high degree of knowledge in multiple disciplines, a lack of financing opportunities for aquaponics, and the fact that the general public doesn't understand what aquaponics is.[49] An aquaponics business may require additional branding strategies compared to hydroponics, which is a technology that is relatively well known at this point in the United States.