WATER USAGE AT DIFFERENT GROWTH STAGES OF CABBAGE AND POTATO PLANTS

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Kwangshin Edward Hwang

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BIOGRAPHICAL SKETCH

Kwangshin Edward Hwang was born in Ku-Ken, Win Lin Shane, Formosa (Taiwan) in 1944. He was raised in the village where most of the residents are still farming. He attended primary and high school in Formosa. In June 1966 he graduated from National Taiwan University with a degree of Bachelor of Science in Horticulture. He was drafted for military service in Formosa in 1967. In 1968 he was a research assistant in National Taiwan University. In September 1968, he commenced studies for the degree of Master of Science at the Department of Horticulture Science, University of Saskatchewan, Saskatoon, CANADA.

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INTRODUCTION

Crop yield depends upon the amount of available water in the soil and the best use of water can be obtained if fertilizer applications, crop varieties and other management practices are optimum for the water available.

Because of evaporation and plant transpiration, a large amount of irrigation water is necessary for improving the agriculture production in some areas. Due to both low relative humidity and low annual precipitation in most parts of the Prairie provinces, water can be the most serious limiting factor for production.

The Department of Horticulture Science at the University of Saskatchewan is interested in research on water usage by horticultural crops. Although the response of some horticultural crops to different amounts of soil water has been studied, this experiment was designed specifically to study the amount of water usage, which included both transpiration and retained water within the plant tissues due to plant growth, at different growth stages by two horticultural crops, namely, cabbage and potatoes.

LITERATURE REVIEWED

Water in Plant Functions

Organic life, according to Maximov (48), originated in water, and the most primitive organisms, such as amoebae and algae, were able to live and to develop only in a water medium. Water has been reported to have many functions in plant life (15, 22, 27). Quoting one of the references(22)

> "This unique compound is the solvent and transportation medium for all foods, hormones, vitamines, and compounds supplying essential elements; it combines with carbon dioxide in the formation of the initial substances in photosynthesis; it combines with starch and related compounds in the formation of glucose in respiration; and more particularly it maintains turgor in living cells".

According to the textbook of plant physiology by Salisbury and Ross (67), the extremely high specific heat, heat of fusion and vaporization of water tended to stabilize plant temperature. They also considered plant transpiration to be an important component of energy transfer between the plant and its environment. Maximov (48) also stated that transpiration reduced the temperature of the leaves, which enabled them to function even in the brightest sunlight without injury. Succulent or cactus plants, according to them (48, 67), survived the dry period because of their ability to utilize water stored in plant, and also because the high water content increased heat resistance in high temperature conditions.

The Absorption of Water

Passive absorption

Devlin (20) stated that an increase in the solute concentration of a cell or a decrease in its turgor pressure would increase the diffusion pressure deficit of its cell sap and, as a result, would increase the uptake of water. It appeared, according to him, that most water absorption occurred through the mediation of osmotic mechanisms and the water was taken up passively.

In a rapidly transpiring plant, according to Kramer's studies (35,36,37,39), the xylem vessels and tracheids were generally in a state of negative tension or reduced pressure. He suggested that transpiration could create tension forces which would be followed by the entry of water into roots. According to him, the root merely acted as an absorbing surface and that absorption of water in transpiring plants was passive. Kramer et al (41) stated that the driving or suction force created by the rapidly moving columns of water was transmitted to the root and that water was literally pulled into the root from the soil.

They stated, however, that the absorption lag caused the development of appreciable water deficits and tensions in the hydrodynamic system of rapidly transpiring plants even when they were growing in moist soil.

Active absorption

Kramer (39) stated that active absorption was attributed to an osmotic gradient. This gradient was caused by ion-uptake. Furthermore, quoting his statement

> "Two general types of explanation have been offered for root absorption: Osmotic explanations assume that roots behave as osmometers in which water moves from the dilute soil across a differentially permeable membrane formed by the cortex to the more concentrated solution in the xylem; non-osmotic explanations assume that water is secreted into the xylem by the surrounding cells by a process dependent on energy released by respiration".

McDermott (50) showed that exudation from the roots of excised sunflower plants growing in soil was greatest when the soil moisture was near the moisture equivalent. At higher moisture contents exudation was lower, probably because of poor aeration. Kramer (35) believed that the osmotic mechanism responsible for active water absorption actually constituted a resistance of the more rapid passive uptake because dead roots allowed more rapid flow than live ones.

Effects of soil temperature on water absorption

Soil temperature has been reported by Kramer *et al* (41) to affect water absorption. According to them, water absorption was significantly reduced at soil temperatures below approximately 20 degrees C(68°F). They stated that the reduction was much greater in warm season crops, such as watermelons and cotton, than in cool season crops, such as bluegrass and *Brassica* species. They suggested that the principle cause of reduced water absorption was the reduction of permeability in the root cell and increase in the viscosity of water itself, which increased the resistance to the passive movement of water through the roots. The decreased metabolic activity of the roots probably was a minor factor in absorption, but decreased root growth at low temperatures has also been suggested by them because of the significantly reduced absorbing surface. Schroeder (69) reported that watering greenhouse cucumbers with cold water resulted in injury, and it seemed probable that the water was cold enough to reduce water absorption and retard growth.

Water Loss from Plants

Guttation (or Exudation)

Devlin (20) stated that plants growing in a moist, warm soil and under humid conditions would often exhibit droplets of water along the margins of their leaves. He also said that loss of water in a liquid form in this manner was called guttation. Kramer (38) demonstrated that guttation or exudation of liquid from the tips and margins of leaves; occasionally from lenticels of twigs; and from wounds and stumps of plants was always due to positive pressure, usually called root pressure, which often developed in the xylem in the range of one to two atmospheres. According to them (20,38), water absorption under these conditions greatly exceeded transpiration and the water was literally "pushed" up the xylem ducts and out through specialized structures at the tip of the vein of leaves called hydathodes.

The phenomenon of guttation, according to Maximov (48), was exhibited by various plants in different degrees; being generally more significant in herbaceous plants than in woody plants. Guttation also responded to the diurnal functions in the plants (12). According to Bunning's report (12), light could trigger these diurnal events, but that the control was compounded by some complex endogenous rhythms.

Transpiration

Devlin (20), as well as Salisbury and Ross (67), stated that transpiration was the loss of water by evaporation from plants. They also stated that it differed from the general process of evaporation because the water vapor did not evaporate from a free surface, but must pass through the epidermis with its cuticle or through the stomata. According to texts on plant physiology (48,54, 68), the water distribution in the plant consisted of three principal processes : the absorption of water from the soil, its translocation to the place of consumption and its loss in the process of transpiration.

Slayter (68) stated that transpiration was basically a passive physical process dependent on the energy input to supply the latent-heat demand, on the availability of water at the evaporating surface and on the transfer of water vapor away from it. Evaporation of water involved in transpiration, according to Milthorpe and Spencer (57), occurred at two main sites, namely, within the epidermal cell walls and within the mesophyll cell walls which line the substomatal cavities. They also stated that the proportion of vapor diffusing by each pathway depended on the resistance of each. Furthermore, Salisbury and Ross (67) stated that the amount of transpiration was proportional to the driving force (vapor pressure difference between the leaf and the atmosphere) and inversely proportional to the resistance.

Factors affecting plant transpiration

Temperature - From the standpoint of the transpiration rate, Salisbury and Ross (67) stated that the gradient in vapor pressure deficit between the leaf and the air was strongly influenced by temperature differences between the leaf and the air. They believed that the internal air of the leaf was saturated with water vapor at the same temperature as the leaf and therefore, if the leaf temperature was higher than the air temperature, the vapor pressure in the leaf would be high and the gradient to the air steep. They also noted that the main causes of temperature difference between the leaf and the air were the absorbed radiation, heat convection and transpiration.

High temperatures of 30 to 35 degrees C (86 to 95 ^{o} F) have also been found to be a factor affecting plant transpiration. According to Heath (30), it caused stomatal closing which might have been due to a rise in respiration rate that caused an increase in carbon dioxide within the leaf tissues.

Atmospheric humidity - The actual concentration of water vapor in the air has been considered by a number of workers (67,70,72) to establish one end of the gradient in the water transpiring pathway. They stated that in some situations, particularly very low humidities and high air temperatures, this might be a major control in the rate of transpiration. Although Salisbury and Ross (67) stated that the difference between actual humidity and potential humidity was of primary importance, Devlin (20) stated that the difference in temperature between the leaf and the air would be a more important factor than atmospheric humidity. Devlin also stated that transpiration could occur into a saturated atmosphere if the leaf temperature was higher than the air temperature.

Light - By its effect upon leaf temperature, incoming radiation, according to Salisbury and Ross (67), influenced both leaf and air temperature. They stated that light also tended to lower leaf resistance to transpiration by causing the stomata to open, but closing of the stomata in response to elevated leaf temperature might tend to increase leaf resistance.

Devlin (20) stated that the stomata of a plant exposed to light were opened and allowed transpiration to proceed. In the dark, however, stomata were closed and transpiration essentially ceased. He suggested that the effects of other environmental factors were, therefore, dependent upon the presence of light. According to Salisbury and Ross (67), the minimum intensity of light for stomatal opening was around 100 to 300 f c. (approximately equivalent to the compensation point). They also stated that the opening would not occur in albino barley plants devoid of chlorophyll. Therefore, the presence of chlorophyll, according to them, played an important role in the opening mechanism. Although the mechanism of stomatal opening has not been made clear yet, they suggested that perhaps the energy of light was converted into chemical energy which was then used to move ions from surrounding cells into the guard cells. This process resulted in an increase in ionic concentration which would cause water to move in osmotically and the stomata would open.

Water stress - According to Pallas et al (63), as well as Salisbury and Ross (67), the water potential in the leaf has been proven to have a powerful control over stomatal opening and closing. They showed that the stomata closed as the water potential decreased. Studying guard cell operation during soil moisture tension, Pallas et al (63) found that there was a decrease in stomatal opening activity as soil moisture tension increased. Salisbury and Ross (67) stated that the effect of water stress on stomatal closure could predominate over low carbon dioxide levels and bright light. They also demonstrated that the effect might be a direct one due to loss of water by the guard cells themselves because such loss was the actual mechanism of closing.

Wind velocity - According to Salisbury and Ross (67), increasing wind lowered the boundary layer resistance both for convection and transpiration by reducing the thickness of the boundary layer over the leaf surfaces. Although the wind could increase transpiration by decreasing resistance, they stated that wind might decrease transpiration by lowering the leaf temperature. Sometimes stomata closed, according to them, when the leaf was exposed to high wind velocities. They stated that this might be caused by the guard cells themselves losing water by transpiration, or the effect might be indirect through leaf temperature.

Measurement of transpiration

Many methods have been suggested for measurement of plant transpiration. Salisbury and Ross (67) suggested that the basic and often limiting problem was to measure the process without influencing it. They, as well as Devlin (20), stated that it was virtually impossible to measure transpiration accurately without influencing it. Salisbury and Ross (67) also stated that these methods usually involved either a measure of the water absorbed or a measure of the water vapor transpired by a plant.

Potometers - In this approach, according to Devlin (20), a cut stem or perhaps a root of a small plant was inserted through a cork and placed in a reservoir of water. Loss of water from the reservoir was usually measured by the movement of a bubble through a small capillary. According to his statement, the problem was that the plant must be cut while immersed in water. This method took advantage of the fact that, generally, the rate of water absorption was very nearly equal to the rate of transpiration. He stated, however, that the rate of transpiration as measured for a cut shoot in a potometer would not necessarily bear any relation to its rate of transpiration while it was still attached to a plant.

Devlin (20) stated that the potometer method was ideal for observing the effects of different environmental factors on transpiration rates. He also stated, however, that this method suffered from the fact that it actually measured water absorption rather than transpiration, and under certain circumstances, the two could vary considerably.

Weighing method - According to Devlin (20) and Meyer and Anderson (54), as well as Salisbury and Ross (67), this method could be used with a small potted plant. The pot might be sealed with water-proof plastic or aluminum foil and weighed during transpiration. Of the methods discussed here, they believed that this one probably influenced transpiration the least. They stated, however, that one difficulty was that the plant would continuously increase in weight as it grew, but the rate of growth was usually insignificant compared to the rate of transpiration. Therefore, they believed that the loss of weight by the plant over a short period of time would be almost completely due to transpiration. Although they also stated that this method was limited in practical application to plants which could be grown in readily portable containers, the transpiration rates of plants as large as mature maize plants have been measured by this method.

Devlin (20), as well as Salisbury and Ross (67), stated that the transpiration rate of excised plant parts, such as leaves, fruits, branches, etc. has been measured by excising the part, immediately weighing and then, after a short period of time, weighing again. Although relative rate of transpiration might be compared in this manner, they stated that transpiration of an excised organ frequently deviated from the normal transpiration of the intact plant. In the initial stages, the rate of transpiration of an excised organ might exceed normal rates, probably because of the release of tensions in the xylem ducts, but after a short period of time, however, transpiration rates would fall off because of a decrease in the water content of the tissue, stomatal closure, permeability changes, etc.

Cobalt chloride method - According to Devlin (20), as well as Meyer and Anderson (54), filter paper disks, which were impregnated with a slightly acidic three per cent solution of cobalt chloride and thoroughly dried, gradually change from blue to pink when exposed to humid air. Likewise, when exposed to a transpiring leaf surface, the color of the cobalt chloride-treated paper would gradually change from blue to pink. They demonstrated that the rate of color change was indicative of the rate of transpiration. This method, however, according to their statement, gave no measure of absolute rates of transpiration because when a portion of a leaf was covered with a piece of paper, the environmental conditions influencing the leaf under the paper were very different from those which would influence it if it was freely exposed to the atmosphere. Under certain conditions, however, they said this method could be used for a determination of the relative rates of transpiration of different species with a fair degree of accuracy, but only when all of the plants were growing under essentially the same atmospheric conditions.

Closed container method - The closed-chamber or cuvette method, according to Salisbury and Ross (67), was a method of collecting and weighing water vapor lost in transpiration. They demonstrated that the plant or plant parts might be placed in a closed container and the relative humidity of ingoing air could be compared with that of the outgoing air. Also, according to Devlin (20), as well as Meyer and Anderson (54), air of known moisture content could be passed over the plant and then passed out over some preweighed water absorbing material, such as anhydrous calcium chloride. They stated that the difference in weight between the calcium chloride receiving air passed over the plant and calcium chloride receiving air passed through the apparatus without the plant was a measure of transpiration. Salisbury and Ross (67) suggested that as the chamber was made smaller, however, it became more difficult to provide a desired environment around the leaf and as the chamber became larger, readings were less accurate because of the lag brought about by the larger volume of air. Nevertheless, they also stated that the environment in the near vicinity of a leaf in such a cuvette could be quite accurately measured and allowed fundamental studies of transpiration to be carried out.

Evapotranspiration

Most studies, according to Gates and Hanks (26), have shown a gradual increase in evapotranspiration from planting to maturity. After maturation transpiration generally decreased. Fulton (24) showed that evapotranspiration from the potato cropped soil could be divided into three stages: during the early season when the soil was wet and the potato foliage covered less than 50 per cent of the surface, evapotranspiration from the crop equalled evaporation from the bare soil; later in the season when the plants were larger, evapotranspiration exceeded evaporation from the bare soil; and when the available moisture stored in the top 15 cm. of cropped soil had been exhausted, evaporation from bare soil and evapotranspiration from the cropped soil again became equal.

Measurements of evapotranspiration

<u>Lysimeter</u> - According to Salisbury and Ross (67), a lysimeter was a weighing device for the measurement of

evapotranspiration from the cropped surface. Lysimeters, in which large plants or even groups of plants were grown in large containers placed on an underground balance, have been used on a large scale. The evapotranspiration was evaluated by Hanks (29) in his studies on evapotranspiration-climate relations for several crops in the central great plains by using lysimeters having an area of 100 x 100 cm and a depth of 90 cm. Also, Fulton's experiments (24) during three consecutive seasons showed that, by use of floating lysimeters, the evapotranspiration from a potato crop and the evaporation from bare soil could be measured.

Solution uptake - Evapotranspiration from snap bean plants, according to Mielke and Peck (55), was measured by continuously recording changes in volume of solution in a sand-nutrient culture system.

Tent method - This method, according to Salisbury and Ross (67), was to duplicate the closed-chamber approach under field conditions. They said that one limitation was that no material yet used for such a "tent" was 100 per cent transparent to varying wavelengths of radiation which affected transpiration by influencing the leaf temperature and stomatal opening. This method, according to them, was developed for direct measurement of evapotranspiration of undisturbed plots of natural vegetation in the field. Decker *et al* (19) reported that the evapotranspiration of undisturbed tamarisk shrubs was measured by use of a circular plot, 3.05 m (10 ft) in diameter and containing shrubs up to

3.05 m (10 ft) high, which were enclosed temporarily in a frameless transparent plastic tent that was ventilated at a known rate. The absolute humidity of inflow and outflow was measured with an infrared gas analyzer, and the evapotranspiration rate was computed as himidity difference multiplied by ventilation rate.

Transpiration and evapotranspiration rate

Kramer (39) stated that transpiration rates could be considered as units of water loss in terms of individual plants and plant parts, as well as in terms of units of vegetation, such as square meters of grass and crop plants, or stands of trees. He also stated that the transpiration of individual plants could be expressed in terms of water loss per unit of plant surface, per unit of fresh weight or per unit of dry weight.

Plant Growth and Development

Cabbage

Cabbage, according to Edmond *et al* (22), developed a short stem and a large terminal bud called the head. They stated that the head was the storage structure and the part used for human consumption. They also stated that it varied greatly in size, shape, texture and color according to the variety.

According to McCollum and Ware (49), as well as Thompson (81,82), cabbage was a hardy, cool-season crop and was at its best during a cool, moist period. It would, however, stand wide variations in temperature. They stated that young cabbage plants of several species, if well hardened, have withstood temperatures as low as 15 to 20 degrees F (-9.3 to -6.6°C) without serious damage. In general, Edmond _et al_(22) stated that the crop thrived best and produced the best heads at temperatures from 50 to 70 degrees F (10 to 21° C).

The specific gravity of the head, according to Mack (46), was taken as the index of its solidity. He stated that the specific gravity of the head was influenced by two factors, namely, the density of the tissues and the compactness of folding of the leaves; the latter factor was without doubt the most important. It was also considered that the specific gravity of the head would be a reliable index of its compactness. Mack (46) concluded form his studies that the various fertilizer treatments had little or no effect on the solidity of cabbage.

In the growth and development of cabbage, according to North (59), the head resulted from the failure of a proportion of the normal complement of leaves to unfold, and the absence of inhibition of leaf unfolding in plants might be related to an early changeover from the vegetative to the reproductive phase. He stated that the head contained reserve sugars and therefore, presumably functioned as a storage organ. He also reported that the head was the aggregate of folded leaves and increased in proportion to the rest of the plant mainly because leaves were initiated and continued to grow in size after leaf unfolding had slowed down or ceased. The time of retardation of leaf unfolding, according to him, was a varietal characteristic which largely determined the time of maturation. It was suggested by him (60,61) that the accumulation of sugars in the young leaves was associated with factors which determined their shape and prevented them from unfolding. He also discovered that there was a negative correlation between the length:width leaf ratio of the seventh to twelfth oldest leaves of a variety and the time it took to form a head.

The effect of planting dates on the heading behaviour of several cabbage varieties was discovered by Knott and Hanna (34). They concluded that the slower the rate of growth of a variety the more the head diameter was reduced as planting progressed from July to February. They also demonstrated that when plantings were made late in the season for a given variety, bolting was likely to be more severe in a quick-growing variety than in one making slower growth.

Cabbage, according to Thompson (82), has been grown on all types of soils from the sands and mucks to the heavy soils. He stated that the maximum availability of phosphorus might be expected between pH 5.5 and 6.5, and because the phosphorus supply was important, he considered this soil reaction range as most satisfactory.

Potatoes

According to Edmond et al (22), the principle climatic factor influencing the growth and yield of potatoes was temperature, and the potato plant thrived best in uniformly cool weather. In general, they stated that the optimum temperature range was considered to be between 45 and 65 degrees F (7 and 18 ^{o}C) with a mean of about 60 degrees F (15.5^{o}C). Engel and Raeuber (23) stated, however, that the optimum temperature for growth during the day was 68 degrees (20^{o}C) and during the night was 57 degrees F(14^{o}C) for all varieties. According to Bodlaender (8), stem elongation increased with increasing temperature until an optimum average 24-hour temperature of 18 to 20 degrees C (64 to 68^{o}F), but no increase in stem length was observed at temperatures below 7 to 8 degrees C (45 to 46^{o}F). The leaves and leaflets were usually larger at lower than at higher temperatures. He also reported that the leaf:stem ratio decreased with rising night temperature. He stated that day temperatures of 18 to 24 degrees C (64 to 75^{o}F) and night temperatures of 6 to 12 degrees C (43 to 54^{o}F) were favourable for tuber growth, but the number of tubers produced decreased with increasing night temperatures.

The soil types for the best production, according to Edmond et al (22), were fertile sandy loams and mucks. They also stated that the addition of decayed organic matter to mineral soils was usually beneficial.

Although bud dormancy and mechanisms for breaking it have not been considered in this thesis, apical dominance should be taken into account as a factor affecting plant growth. Because of the initial differences in bud size, according to Milthorpe and Moorby (56), the smallest sprouts were gradually inhibited until only two to four buds on each seed tuber continued to grow. According to them (56), Goodwin showed that the inhibition could not be reversed by supplying nutrients to the inhibited buds, but this treatment increased the growth of the dominant sprouts. It was suggested by him that this correlative inhibition arose from auxin or some other substance moving from the apical regions of growing sprouts into the tuber where it induced the production of an inhibitor.

Munster and Keller (58) found that the larger seed-potatoes gave better emergence, vegetative growth and tuber yield. The advantage of using small tubers, according to them, was that they cost approximately one-half that of normal-sized tubers. They also stated that in favourable situations sprouted seed-potatoes of small size (30-35 mm) were as productive as non-sprouted tubers of normal-size (35-55 mm). Svensson (78) demonstrated that increasing the size of sets from 5 to 15 and 30 gm gave more vigorous plant development and increased the number of stolons and tubers per stem. As the number of stems per hill increased from one to seven, according to him, the number of tubers per hill increased, but the number of stolons and tubers per stem decreased. He also showed that deep planting of sets gave shorter stolons and longer stem internodes than did shallow planting. Due to competition between the tubers for a limited supply of photosynthate and mineral elements, Milthorpe and Moorby (56) stated that widely spaced plants gave a large proportion of their yield as larger tubers, whereas multistemmed or closely spaced plants provided a much higher proportion of small tubers, and Munster and Keller (58) found that more stolons and tubers per stem were formed from sets with wider spacing than narrow spacing in the row.

According to Mclean (51), three important factors, namely, the length of days, the temperature and the amount of nitrogen available to the plant have been considered to be involved in potato growth (plant growth, tuberization or tuber growth). He stated that the greatest plant growth occurred if the plants emerged under long days or into increasing day lengths when the temperature was warm or increasing and when nitrogen available to the plant was high or increasing. Tuberization, according to him, on the other hand, was encouraged by just the opposite conditions, which were short days or decrease in day lengths, lower temperatures or decrease in temperatures, low nitrogen or decreasing nitrogen.

Studying the changes of growth phase, Werner (84,85) stated that whenever carbohydrates were manufactured in excess of the capacity of the plant to build up new tissues or beyond the respiration requirements, they accumulated them in the tubers after a transitory period of storage in the leaves, stems and stolons. Quoting from his reports such accumulation has been found to occur:

"a. when days are shortened,

b. when the temperature is reduced,

c. when the external nitrogen supply is reduced, and

d. when any of these things occur in combination, etc."

He also concluded that probably all of these factors were really carbohydrate-nitrogen effects. Tubers grew, however, according to Engel and Raeuber (23), most rapidly with less than eight hours light per day, while tops grew fastest with more than 12 hours per day. Leopold (44) and Smith (73) have stated that the time of tuber development was associated with a retarded growth of aboveground parts, followed generally by a senescence of the aerial parts at the time of completion of tuber growth. According to Leopold (44), Wellensiek stated that many treatments which could suppress vegetative growth have been found to promote tuber formation in potato, for example, tubers could be encouraged by pinching back the vegetative growing points.

Sparks and Woodbury (75) demonstrated that the position and degree of development of the inflorescence was probably the best criterium for stage of growth. They also showed that the defoliation practice, regardless of amount or stage of growth, resulted in smaller sized tubers, but the later in the development of the plant that defoliation occurred, the greater the reduction in starch content in the tubers. The levels of dry matter, starch and ascorbic acid, according to Carlsson (13), were very low in newly formed tubers. Appleman and Miller (3), however, showed that ascorbic acid increased until one to two weeks before haulm die-back and then declined, while growth and ripening of tuber were associated with a marked drop in sugar content. With the sugar decline there was an increase in the starch content.

The primary feature of tuber growth, according to Lugt _et al_ (45), was that the growing internodes of the apical bud expanded radially rather than elongated as they did during stolon or sprout growth. Ivins and Bremner (31) stated that the final yield depended upon the rate of tuber bulking and the length of time over which it took place. They also said that after initiation, yield increased exponentially for a time and then the rate fell off with tuber growth ceasing completely with the death of the foliage. Both the rate of tuber growth and the time of foliage senescence, according to them, were related to the amount of leaf growth made by the time of tuber initiation. With the progress curves for tuber growth, according to Plaisted (64), an exponential character was shown. He stated that the great bulk of the tuber-filling activity occurred very near the end of the growth season. Tuber growth, by roughly equal activities of cell division and enlargement, was also noted by him.

The tuber shape index (2 x length : width + thickness) and tuber : vine ratio were used to indicate tuber growth by Metzger (53). He showed that both values generally decreased either due to the late planting or the early harvesting treatment. The fresh weight of each tuber could also be used as an indication of the tuber growth, according to Smith (73), by classifying the tubers into different weight ranges, i.e. less than 1 gm, 1 to 10 gm, 10 to 20 gm, 20 to 50 gm, 50 to 100 gm, 100 to 200 gm, and more than 200 gm, etc.

Although the mechanism which caused potato stolons to cease elongating and to swell to form tubers has still not yet been made clear, some physiological phenomena of tuberization have been reported. According to Bodlaender (7) and Gregory (28), plants grown under short-day conditions developed flower primordia and they set tubers seven to ten days earlier than did plants under long-day conditions. Therefore, they suggested that the effect of long days only delayed, but did not inhibit tuberization. Leonard (43) stated that long days retarded the onset of tuber formation, but for a short time after its onset a short photoperiod accelerated the development of tubers. In the later part of summer, however, according to him, increase in tuber yield was greater under long-day than short-day conditions.

Low temperature promotion of tuberization had been noticed by Werner (84). He stated that the low-temperature induction of tuberization in plants also caused a systematic inhibition of vegetative growth. Although both low temperature (55.4°F, 13° C) and short-day (8 hours light per day), according to Gregory (28), were favourable for tuberization, the most recent statement by Salisbury and Ross (67) was that tuber formation did not require short days, but would proceed at any daylength (a day-neutral response) if the night temperature was below 20 degrees C (68 degrees F). They stated that tuberization was optimal at night temperatures of about 12 degrees C (53.6 degrees F) and that the low temperature stimulation was detected by the tops of the plants rather than the underground parts. Thus, under long days, according to them, no tubers would form at any soil temperatures unless the tops were exposed to low temperatures.

According to Leopold (44), Booth stated that both auxins and gibberellins might be involved in the tuberization of potatoes. Okazawa and Chapman (62) also found that several kinds of gibberellin-like substances were found in the potato leaves, the content of which was much higher in young leaves growing under long-day conditions. Therefore, they concluded that the natural gibberellins seemed to be involved in the control of tuber formation in the potato plants as an inhibiting factor.

Chapman (14) and Gregory (28) had noticed that a hormone-like substance which was induced under short-day conditions was graft transmissible. Although Chapman (14), by girdling the plants, showed that the tuberizing stimulus to produce tubers moved characteristically down the plant, more recently research by Okazawa and Chapman (62) has shown that neither the inhibitory gibberellins nor the tuber-forming stimulus was polar in its movement in the potato plant. According to them, plants tuberized regardless of the fact that the growing points were trained downward and held well below the level of the roots.

Barker (6) found that tubers could be formed from meristems in *in vitro* tissue culture. Carbohydrate contents were very high in tuberizing plants, and Mes and Menge (52) found that the addition of sugars to a piece of stem could promote tuber formation in *in vitro* tissue cultural conditions. In some instances, according to Lawrence and Barker (42), however, only an adequate sugar supply was accompanied by a rapid change from the vegetative to the tuberized condition. They also showed that there was no direct need in tissue culture for any external source of auxin nor any requirement for an appropriate light/dark cycle or temperature level as a preliminary to tuber onset. Treatment with 2, 3, 5-triiodobenzoic acid (TIBA), however, did retard tuber formation temporarily, but failed to prevent it. They also stated that the TIBA effect was not overcome by addition of indole-3-acetic acid (IAA).

Water Effects on Plant Growth

Some indirect evidence indicating that transpiration might have an influence on the growth of some plants has been obtained by Winneberger (86). He observed that buds of the hardy pear ceased to grow under conditions of high humidity and that under the same conditions the growth of sunflower plants was reduced to about one-half of the normal. He also concluded that transpiration was a necessary factor in the normal growth of these two plants. Martin and Clements (47) reported, however, that the total plant growth decreased with increasing wind velocity when the experiments were carried out over a long period of time.

Shaw and Laing (70) stated that water deficits sufficiently severe to cause wilting also reduced growth. On the other hand, they stated that abundant soil water also inhibited plant growth in some cases because the water requirement depended on plant species and their environments. They also stated that the final yield of a crop was the integrated result of a number of interrelated effects on different physiological processes. According to them, water stress could affect the processes of photosynthesis and respiration. Leopold (44) considered that water was am important ecological factor in photosynthesis through its control of stomatal opening and its effects on wilting of leaves. Brix (11) and Kramer (40), as well as Pallas _et al_(63), were all concerned with soil water availability and photosynthesis. According to them, as soil moisture tension increased, photosynthesis decreased or dropped to the compensation point. If the leaf turgor pressure remained high, according to Ashton (4), as well as Thomas and Hill (80), the diurnal course of photosynthesis corresponded closely to that of light intensity. Dastur (17), as well as Dastur and Desai (18), however, found that a direct correlation between the rate of photosynthesis per unit of leaf area and the water content of the leaf existed. Shirk (71) stated that the respiration rate of seeds decreased as water stress increased. Generally speaking, according to Brix (11), water deficiency caused decreases in photosynthesis and respiration rates.

According to Alderfer (1), as well as Alderfer and Ranadhar (2), most of the vegetable crops were affected by high soil-moisture stress during any stage of growth, resulting in reduced yield and quality of marketable products. They, as well as Janes and Drinkwater (32), stated that the yield reduction was greatest when periods of high soil moisture stress and atmospheric stress coincided.

Cabbage

Alderfer and Ranadhar (2) reported that water stress affected total yield and head weight of cabbage most when severe plant-water deficits occurred during head formation and enlargement. According to Salter and Goode (68), Nelson showed that the highest yield of cabbage was produced from plants never subjected to high stress conditions. According to them, Nelson also stated that stress conditions prior to and after heading reduced yield by 14 and 36 per cent, respectively. Vittum (83) also showed that low soil moisture was harmful at any time during the development stages. These results (2,68,83) suggested that a plentiful soil moisture supply was particularly important for cabbage after head formation had started. Drew (21), as well as Janes and Drinkwater (32), stated that the later the dry period occurred the more the yield was decreased. Their results could not be explained in terms of a correlation with evaporative conditions during the different stages of growth since their experiments showed the same results during either the earlier or later growing season.

Irrigation studies by Janes and Drinkwater (32), as well as Vittum (83), showed that a record of changes in soil moisture was particularly useful in determining the time to irrigate cabbage. For the soil (Merrimac fine sandy loam) used in their experiments, the changes in soil moisture at the six- to eight-inch depths were associated with the growth of the crop. They also showed that the growth of cabbage was slowed down when the moisture at these depths was reduced to 12 per cent (2 atmospheres of soil moisture tension) or lower. Although it has been recognized that cabbage plants removed moisture from a greater depth than six inches, Janes and Drinkwater (32) suggested that vegetable crops should receive an inch of water a week to maintain water in the upper part of the available water range at the six-inch depth. According to Bargrov (5), however, the highest yield of cabbage was obtained by maintaining the soil moisture level between the beginning of the vegetative period and maturation at not less than 80 to 85 per cent of field capacity. He also stated that during the maturation period a level of 70 to 75 per cent was necessary.

Salter and Goode (68) drew a conclusion based on the effects of different irrigation treatments on the yield of cabbage. They stated that maximum growth and yield could only be obtained when a plentiful supply of water was available to the plants throughout growth, and that dry conditions during head formation would cause the biggest reductions in yield.

Potatoes

Salter and Goode (68) stated that observations made over 70 years ago indicated the need to irrigate potatoes at certain stages of growth. According to them, Buffum, in 1892, reported that irrigation before the tubers were set resulted in a greater number of potatoes being formed than the plants could properly support and few of them became large enough for market. Some other reports in the early 1900's, cited by them, demonstrated that once the tubers had set, irrigation was required sufficiently often to keep the soil moisture high until the crop matured. They stated that the highest yield of marketable potatoes was obtained when water was first applied as the tubers began to form and thereafter as often as necessary until maturity, but irrigation before tuber formation resulted in a lower yield. According to them (68), both Harris and Palmer obtained similar results and emphasized the importance of an even supply of water after tuber formation. The three growth developmental stages of the plant, according to Steineck (76), were stolon formation, tuber setting and tuber growth. He suggested that irrigation must ensure an adequate supply of water to the plant from the time of stolon formation until maturity, and he pointed out that the generally accepted view that the best time for irrigation was during flowering was not always tenable. Some European and Russian research workers about 1950 were cited by Salter and Goode (68). They stated that the best time to irrigate for increased yields was at the start of flowering. Taylor and Slater (79), however, have suggested that potatoes were most sensitive to shortage of water from planting until the time the tubers were fully formed, while Bradley and Pratt (10) stated that when soil moisture was low during the period of tuber-set, increased tuber-set might be expected to result from irrigation. When moisture was ample for a good tuber-set, but was low later in the season, better tuber size might be expected to result from irrigation.

Struchtemeyer (77) showed that the greatest effect of water shortage on reducing yield was when the shortage occurred in the last half of the growing season.

Jones and Johnson (33) showed that a drought early in the growing season had much less effect than one of the same duration which occurred later on when the tubers were growing. According to Salter and Goode (68), Llewelyn showed that irrigation at the time of tuber formation produced a higher yield of tubers than irrigating at the time of stolon formation or during the early bulking period of the crop, while postponing irrigation until the beginning of the main bulking period resulted in the lowest yield. Fulton and Murwin (25) found that the increase in yield of potatoes grown under irrigation was due to an increase in tuber size rather than an increase in the number of tubers set.

The optimum soil moisture, according to Engel and Raeuber (23), was 80 per cent of field capacity for tuber growth and slightly less for vegetative growth.

The effects of irrigation at different stages on the quality of potato tubers have been noticed by several workers (65,66,68). They reported that an irregular water supply to the plants while the tubers were growing caused knobby tubers resulting from secondary growth associated with rewetting after dry conditions. Sparks (74) showed that two types of potato malformations, namely knobby tubers caused by secondary lateral growth and off-types caused by secondary longitudinal growth occurred, Robins and Domingo (66) found that spindle shaped tubers resulted when regrowth occurred after dry conditions, and this happened because the new growth and enlargement took place at the tip of the tuber while the older portion remained stunted. Cracking of the tubers, according to Salter and Goode (68), also occurred when a mid-season shortage of water was followed by an adequate moisture supply. Depletion of the available soil moisture at the end of the season was suggested by McCollum and Ware (49) to reduce the incidence of cracking and to hasten tuber maturity.

Box et al (9) found that tuber specific gravity was highest under conditions of high moisture supply and low fertility treatment. Several workers (33,73), however, demonstrated that irrigation late in the season lowered the specific gravity of the tubers.

MATERIALS AND METHODS

Location and Crops

During the past three years, 1968, 1969 and 1970, a number of experiments have been carried out within the Department of Horticulture Science at the University of Saskatchewan, Saskatoon to determine the total transpiration per plant at different growth stages, as well as the estimated total water usage by cabbage and potato plants.

Trials and Design

The summary of trials and design are presented in Table 1. The transpiration measurements and the growth measurements were conducted once every week. The time period between the first and the last measurement included most parts of the life cycle (e.g. vegetative growth, reproductive growth, maturation, senescence, etc.) with potato, but no attempt was made to develop the flower stalks of the cabbage plants before the end of the experiment.

Random selection within the blocks was used for the sampling process. Thus, the effect of plant growth on transpiration and the plant growth itself could be determined statistically.

Table (1). Trials and Designs

Crops and trials	Stage	Duration	Number of weeks of measurements	Replication	Growing locations	Locations of transpiration measurements
Cabbage						
C-1	to maturity	May 12 to Aug.25, 1969	11	8	greenhouse	greenhouse and growth chamber
C-2	to maturity	May 12 to Aug.21, 1969	9	5	field	field
C-3	young plant (before trans-planting)	Jan.19 to Feb.23,1970	4	8	growth chamber	growth chamber
Potato						
P-1	to maturity	Jan.21 to Apr.15, 1969	9	4	greenhouse	growth chamber
P-2	to maturity	May 12 to Aug.12, 1969	12	7	greenhouse	greenhouse and growth chamber
P-3	to maturity	May 25 to Aug.24, 1969	8	5	field	field
P-4	young plant (1st. and 2nd. week after emergence)	Jan.19 to Feb.5, 1970	2	6	growth chamber	growth chamber

Production of the Experimental Plants

Varieties

The cabbage cultivar Golden Acre was used in all cabbage trials. This variety is an early cabbage, but small in size. Heads are round, solid, and weigh about two pounds.

The potato cultivar Norland was used in all potato trials. This variety is an early-maturing, red-skinned variety and has a high percentage of smooth, attractive marketable tubers. The quality is considered fair to good (16).

Container and soil mixture

In the trials held to maturity stage (Trials C-1, C-2, P-1, P-2, P-3), circular plastic containers (height 23.2 cm, top diameter 20.4 cm, bottom diameter 19.1 cm) were used as containers. Each container held approximately 6145 cubic centimeters of soil which had an air dry weight of about 7000 grams. Each container had 35 holes (diameter 13/64 inch) drilled in the bottom for drainage.

The containers for the young plant trials (Trials C-3 and P-4) were 3-inch plastic pots for cabbage and 3-inch clay pots for potato.

The soil mixture used for all these trials was the ratio of 1 soil : 1 sand : 1 peat moss. The field capacity of this mixture was 49 per cent (based on dry weight).

Environmental conditions during growing period

The potato plants in Trial P-1 were treated with artificial light (2000 fc at soil surface) for eight hours per day during the winter in the greenhouse.

Later trials in the greenhouse (C-1 and P-2) were not treated with artificial light, however, and only received the sunlight which passed through the greenhouse glass which was shaded with Garland's compound during the summer. The Trials C-2 and P-3 received only natural light in the field.

To maintain the temperatures as close to 60 degrees F (night) and 70 degrees F (day) as possible in the greenhouse during the summer growing season (Trial C-1 and P-2), an evaporative cooling system was used.

The plant materials for the young plant trials of both cabbage and potato (C-3 and P-4) were grown in the growth chamber under controlled environmental conditions, i.e. 70 degrees F (21° C) during the day, 60 degrees F (15.6° C) during the night, and light intensity of 2500 fc.

Cultural practices

Cabbage - Two to four cabbage seeds were sown directly in the 3-inch plastic pots for the young plant trials (C-3) while the seeds were sown in jiffy pots for the trials held to maturity (C-1 and C-2). The size of the jiffy pots was 3 x 3 x 5 centimeter. These plant materials, during their seedling stages, received a 20-20-20 (Plant Prod) nutrient solution at a concentration of 1:400 (by weight) once every week until transplanting. Thinning to one plant per pot was carried out when the young plants had started to grow the first true leaf.

In the greenhouse trial (C-1) the transplanting was done when two true leaves had been attained on the plant. For the field trial (C-2), however, the plants were placed in a cold frame when the second true leaf stage had formed and were hardened for a week before transplanting into containers that were placed directly into the field.

An application of 18.9 grams of 11-48-0 granular fertilizer to each container was used in Trial C-1 and C-2 and mixed into the top four inches (10.2 cm) of the soil by hand before transplanting

Potato - The potato seed-tubers were cut into uniform size by use of a potato eye-scoop. Each seed-piece, with at least one good eye, weighed about 30 grams. Ethanol (95%) was used during the cutting process to disinfect the eye-scoop. The seed-pieces and the containers were also treated with a solution of the fungicide Captan (concentration 1:400 by weight).

The depth of planting in these trials (P-1, P-2 and P-3) was one inch from the level of soil surface to the eye of the seed-piece, but in Trial P-4 the depth was only one-half inch. Only one stem per pot was allowed to grow throughout the whole experimental period in all potato trials. Bamboo stakes were used to hold the stem as upright as possible.

The plants in Trial P-1 were supplied with 5 grams of 20-20-20 per pot while the plants in Trials P-2 and P-3 were supplied with 15.6 grams per pot. The fertilizer was mixed into the top layer of the soil (approximately four inches) by hand before planting. No further fertilizer application was used. In Trial P-4, only the 20-20-20 (1:400) nutrient solution was used on a weekly basis.

Data Collection

Measurement of transpiration

The weighing method for determining transpiration was used in all these trials. At the start of the experiment, four pots were filled with the soil mixture and watered similarly to the treatment pots. These four pots were used for the control treatments and the plant transpiration was calculated by the water loss difference between the planted pot and average of the control pots. The control pots were placed between the planted pots to create as close to the same shading effect as possible.

With the exception of Trials C-1 and P-2, the soil of the randomly selected pots was saturated with water, drained for one hour, placed in an undrilled container to collect any further drainage, weighed, held for a 24-hour period under the transpiration measuring conditions (Table 1), weighed again and then harvested. The plant materials for the transpiration measurements in a two-hour period in the greenhouse (C-1 and P-2) were not harvested, but were placed for a 24-hour period in the growth chamber the next day. In these two trials the weight of the plant soil and container after drainage in the greenhouse trial the previous day was re-established by the addition of water before being placed in the growth chamber.

Measurement of plant growth

The plants were removed and the weight of roots, stem and head, as well as the unfolded leaves, was taken into account for the weight of the total cabbage plant, while the weight of roots, tubers, stems and leaves was used for the weight of the total potato plant. The plant roots were collected by a washing process and then surface dried by use of paper towels.

Dry weight of the total plant, as well as plant parts, was obtained after oven drying for a 24-hour period at 75 degrees C (167° F). With the exception of the greenhouse Trial C-1 and P-2 where the plants were not harvested, all of the following measurements were taken once every week during the experimental period.

Cabbage trials - in the cabbage trials they were,

1. Fresh weight of the total plant in grams (C-1,2,3),
2. Fresh weight of the unfolded leaves in grams (C-1,2),
3. Fresh weight of the head in grams (C-1,2),
4. Dry weight of the total plant in grams (C-1,2,3),
5. Dry weight of the unfolded leaves in grams (C-1,2),
6. Dry weight of the head in grams (C-1,2),
7. Equatorial diameter of the head in centimeters (C-1,2) and
8. Polar diameter of the head in centimeters (C-1,2).

Potato trials - in the potato trials they were,

1. Fresh weight of the total plant in grams (P-1,2,3,4),
2. Fresh weight of the leaves in grams (P-1,2,3),
3. Fresh weight of each tuber in grams (P-1,2,3),

4. Dry weight of the total plant in grams (P-1,2,3,4),
5. Dry weight of the leaves in grams (P-1,2,3),
6. Dry weight of each tuber in grams (P-1,2,3),
7. Height of the stem in centimeters (P-1,2,3),
8. Equatorial diameter of tuber in centimeters (P-1,2,3),
9. Polar diameter of the tuber in centimeters (P-1,2,3)

Calculations and Statistical Analysis

The growth rates were calculated according to the slopes or tangents at the specific time on their growth curves (67).

The transpiration rates per plant or per gram of plant weight, as well as the increases in weight due to plant growth at the different growth stages, showing significant differences in the analysis of variance were subjected to a Duncan's multiple range test to determine exactly when the significance occurred.

Transpiration per plant was analyzed to establish the relation to plant growth by use of the linear regression analysis, and least significant differences (L.S.D.) were used as a test for significance. The correlation coefficients were also calculated.

RESULTS AND DISCUSSION

Cabbage Trial C-1

Plant growth and development

The plant materials for this trial were grown in the greenhouse during the summer of 1969. The average growth from this trial is presented in Table 2, while the growth rates of the whole plant, as well as the plant parts, are presented in Table 3. Statistical significance and growth increase or decrease from the previous record is indicated under the actual average weight values.

It is obvious from Table 2 that there were very significant increases of total fresh weight of the plant with increments of plant age from 50 up to 99 days after sowing. The increases of total dry weight were quite similar to the fresh weight, however, the significant increases in total dry weight did not occur until seven days later than they did with the fresh weight. The growth rates of the total plant (Table 3) also showed that the maximum weekly rate of increase in fresh weight was seven days earlier than it was in the dry weight, i.e. 78 and 85 days after sowing, respectively. North (61) showed that the accumulation of sugars in the young leaves was associated

Table (2). Average Weights and Measurements, as well as a Summary of Significance from Analysis of Variance Studies on Cabbage Plants (Trial C-1)

Measurements	Days after sowing 36		43		50		57		64		71		78		85		92		99		106
Total fresh weight of the plant (gm)	16.3	N.S.	47.3	N.S.	124.9	**	245.5	**	403.3	**	606.2	**	767.1	**	1021.0	**	1283.2	**	1411.0	N.S.	1396.1
Total dry weight of the plant (gm)	1.1	N.S.	3.4	N.S.	9.2	N.S.	15.8	**	30.6	**	43.8	**	55.9	**	74.0	**	93.2	**	111.1	N.S.	116.6
Fresh weight of the unfolded leaves (gm)	14.6	N.S.	43.0	*	111.7	**	212.9	**	328.5	**	449.1	N.S.	422.5	N.S.	461.7	*	520.3	*	451.2	*	374.5
Dry weight of the unfolded leaves (gm)	0.9	N.S.	3.0	N.S.	8.0	N.S.	13.2	**	24.2	*	31.5	N.S.	31.3	N.S.	34.6	*	40.9	N.S.	40.8	N.S.	38.2
Fresh weight of the head (gm)	-		0.2	N.S.	1.8	N.S.	8.9	N.S.	32.0	N.S.	96.5	**	282.6	**	487.4	**	675.2	**	880.3	N.S.	926.9
Dry weight of the head (gm)	-		0.02	N.S.	0.15	N.S.	0.64	N.S.	2.51	N.S.	6.71	**	17.88	**	31.15	**	42.61	**	59.45	N.S.	64.54
Equatorial diameter of the head (cm)	-		0.65	**	2.20	N.S.	2.80	**	4.19	**	6.79	**	9.46	**	11.15	**	13.26	N.S.	13.36	N.S.	13.08
Polar diameter of the head (cm)	-		1.18	N.S.	1.43	**	4.11	*	5.63	**	8.05	**	10.25	*	12.06	N.S.	12.13	N.S.	12.45	N.S.	13.35

N.S. no significant iifference   * 5% level significance   ** 1% level significance

Table (3). The Growth Rates per Week of the Total Plant and Selected Plant Parts at the Different Ages of Cabbage Plants (Trial C-1)

Measurements	Days after sowing 36	43	50	57	64	71	78	85	92	99	106
Total fresh weight of the plant (gm)	20	60	100	145	190	213	215	210	140	70	20
Total dry weight of the plant (gm)	1.8	4.3	6.3	8.5	13.0	14.3	16.8	18.8	18.0	9.0	3.5
Fresh weight of the unfolded leaves(gm)	17.0	43.3	83.3	98.0	96.7	57.3	30.0	8.0	- 1.0	- 27.0	-177.0
Dry weight of the unfolded leaves (gm)	1.5	3.1	4.2	7.2	9.0	5.0	3.6	2.1	1.0	-0.1	-0.8
Fresh weight of the head (gm)	-	0.5	2.8	10.0	41.5	115.0	207.5	207.5	207.5	92.0	20.0
Dry weight of the head (gm)	-	0.03	0.14	1.00	2.50	5.80	13.50	13.50	13.50	8.20	5.0
Equatorial diameter of the head (cm)	-	0.7	1.0	1.3	1.9	2.5	1.7	1.7	1.0	0.5	0.2
Polar diameter of the head (cm)	-	0.4	1.0	1.7	2.3	2.4	0.9	0.9	0.3	0.5	0.8

with factors which determine their head formation. The sugar accumulation probably also induced the plant to increase in dry matter during the later growing period as shown by these results.

The increases in weights of the different parts of the plant have also been used to indicate the relative growth and their relation to the whole plant (Figures 1 and 2). With the unfolded leaves the rapid increases in fresh weight were found from 43 to 71 days, and significant increases in dry weight were found from 57 to 71 days after sowing (Table 2). There was also a significant increase in both fresh and dry weights between 85 and 92 days. According to these results, it is obvious that the rapid growth of the total plant during the early growing period was mostly due to the significant increases in both fresh and dry weights of the unfolded leaves. It was also shown that the significant increases in the fresh weight of the unfolded leaves were earlier than with the dry weight. The maximum weekly rate of increase in the fresh weight of the unfolded leaves was found at 57 days (Table 3) while with the dry weight it was 64 days after sowing. The negative values in Table 3 or decreasing fresh weights (Table 2) of the unfolded leaves after 92 days were due to the loss of leaves through senescence from the lower positions on the plants.

The significant increases in both fresh and dry weights (Table 2) of the head were found to occur only

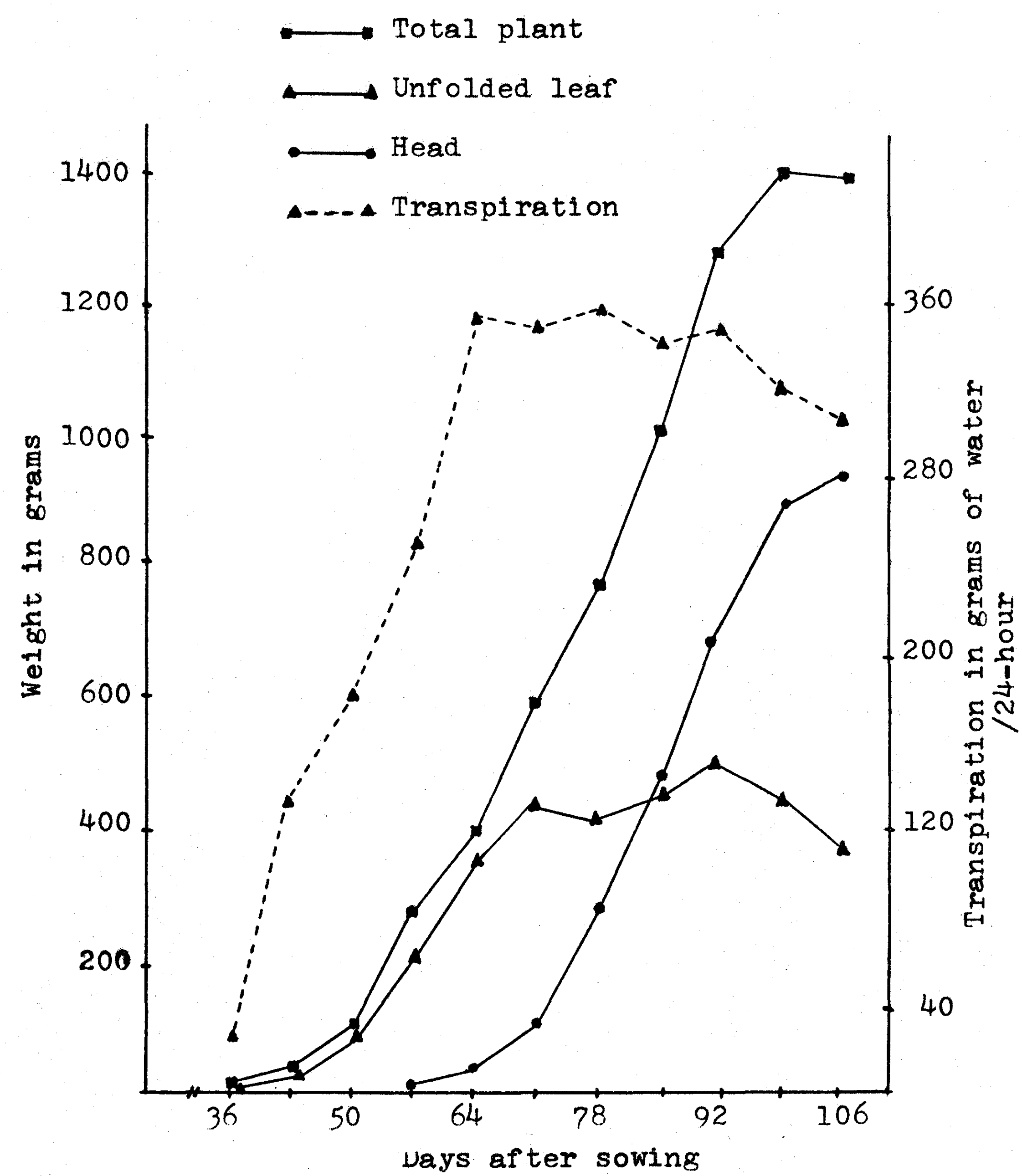

Figure 1 : Fresh weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the growth chamber, at different ages. (Cabbage Trial C-1, summer 1969)

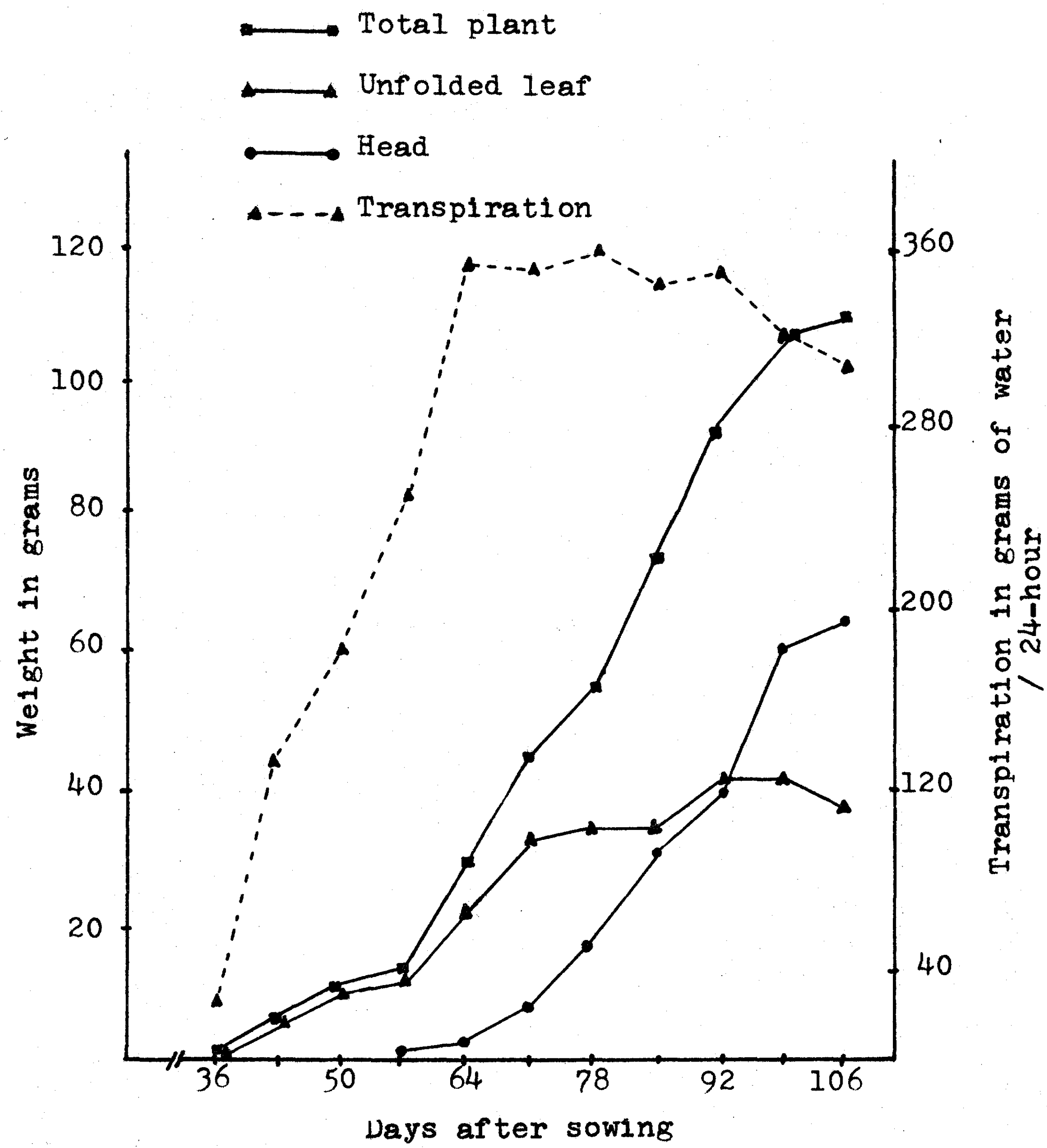

Figure 2 : Dry weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the growth chamber, at different ages. (Cabbage Trial C-1, summer 1969)

after 71 days and to continue until 99 days. The maximum weekly rate of increase in both fresh and dry weights of the head (Table 3) was found during the period from 78 to 92 days after sowing. Because fresh weight and dry weights increased during the same period, it is obvious that weight increase of the head was mostly due to a storage or accumulation mechanism. This period of maximum rate of increase in the weight of the head also coincided with a decrease in both the fresh and dry weights of the unfolded leaves. There is no doubt that the significant increases in the fresh and dry weights of the head caused most of the increase in the weights of the total plant during the later growing period.

The volume increase of the head (both equatorial and polar diameters) was more rapid during the early head growth although weight increase was shown later (Table 2). Both the equatorial and polar diameters were found to increase significantly from 43 to 85 days (except from 50 to 57 days), and from 50 to 85 days, respectively. It is obvious from the weight values that the increase in weight of the head was caused by increased compactness or firmness while the volume of the head did not increase as rapidly.

The significant switch over from the vegetative growth phase to the storage growth phase occurred during the period from 64 to 78 days after sowing, although the physiological changes might be induced in cells or tissues before this period. During this period, however, increases in the growth rates of the head and decreases in the growth rates of the unfolded leaves were found (Figures 3 and 4).

The total growing period, according to the growth pattern of the cabbage plant in this experiment, was arbitrarily divided into four stages. They were:

I. The unfolded leaf growth stage (up to 64 days);

II. The transition growth stage, including head formation (from 64 to 78 days);

III. The storage or head enlargement stage (from 78 to 99 days); and

IV. The head maturity stage, including plant senescence (after 99 days).

Plant transpiration

The average results of plant transpiration in every two-hour period from 6 a.m. to 10 p.m. are presented in Table 4. There were highly significant increases up to the two-hour period of 12 noon to 2 p.m. with the maximum transpiration per plant. After this maximum transpiration period, rapid decreases in transpiration were also found although there seemed to be a levelling off of the transpiration rate from 2 to 6 p.m. Although the highest temperature and the lowest relative humidity during the day were found in the two-hour periods of 2 to 4 p.m. and 4 to 6 p.m., respectively, these two periods did not show the highest transpiration per plant. It is not known from the

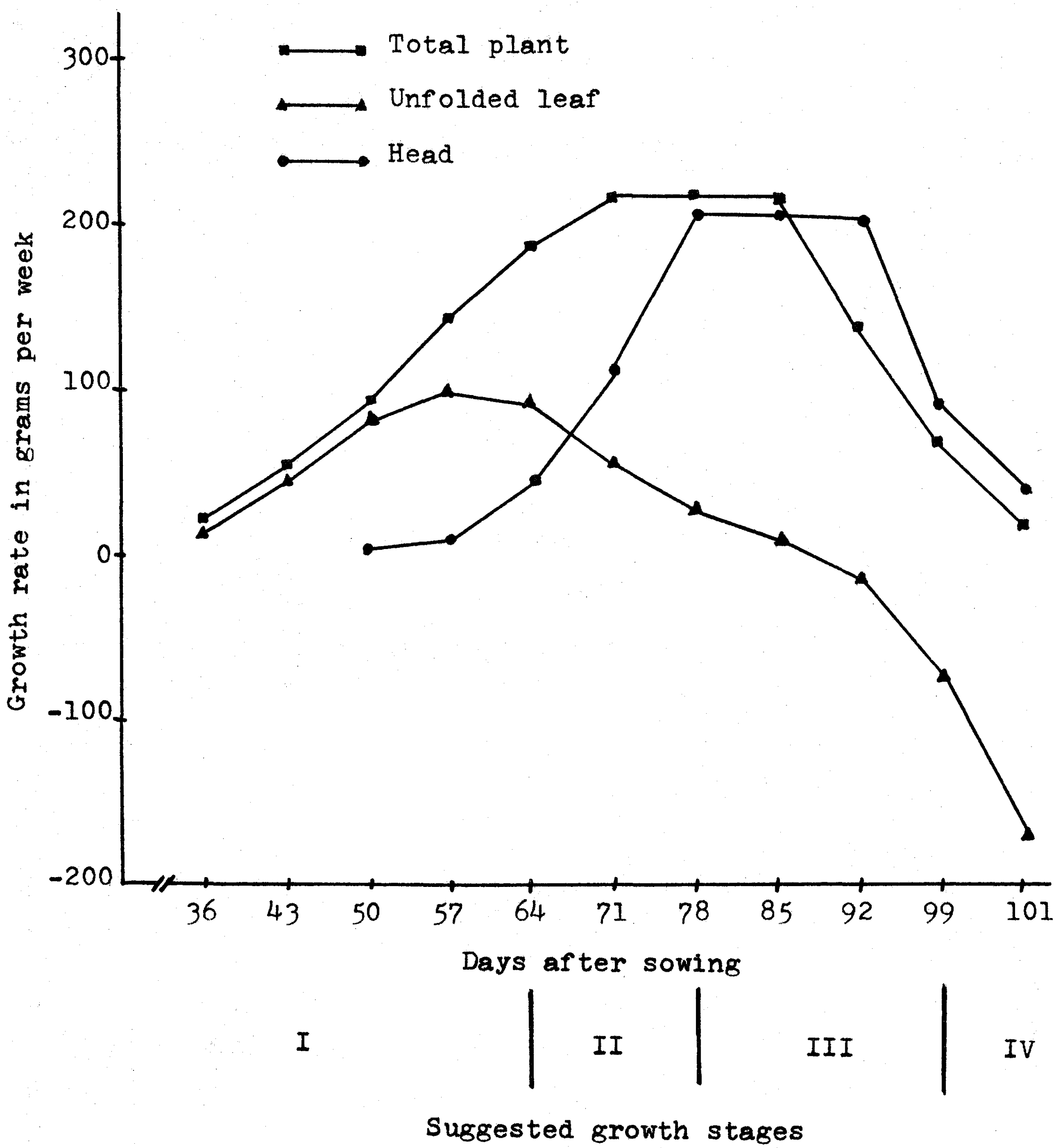

Figure 3 : Growth rates in grams of fresh weight per week of the total plant and plant parts in the greenhouse, as well as the suggested growth stages. (Cabbage Trial C-1, summer 1969)

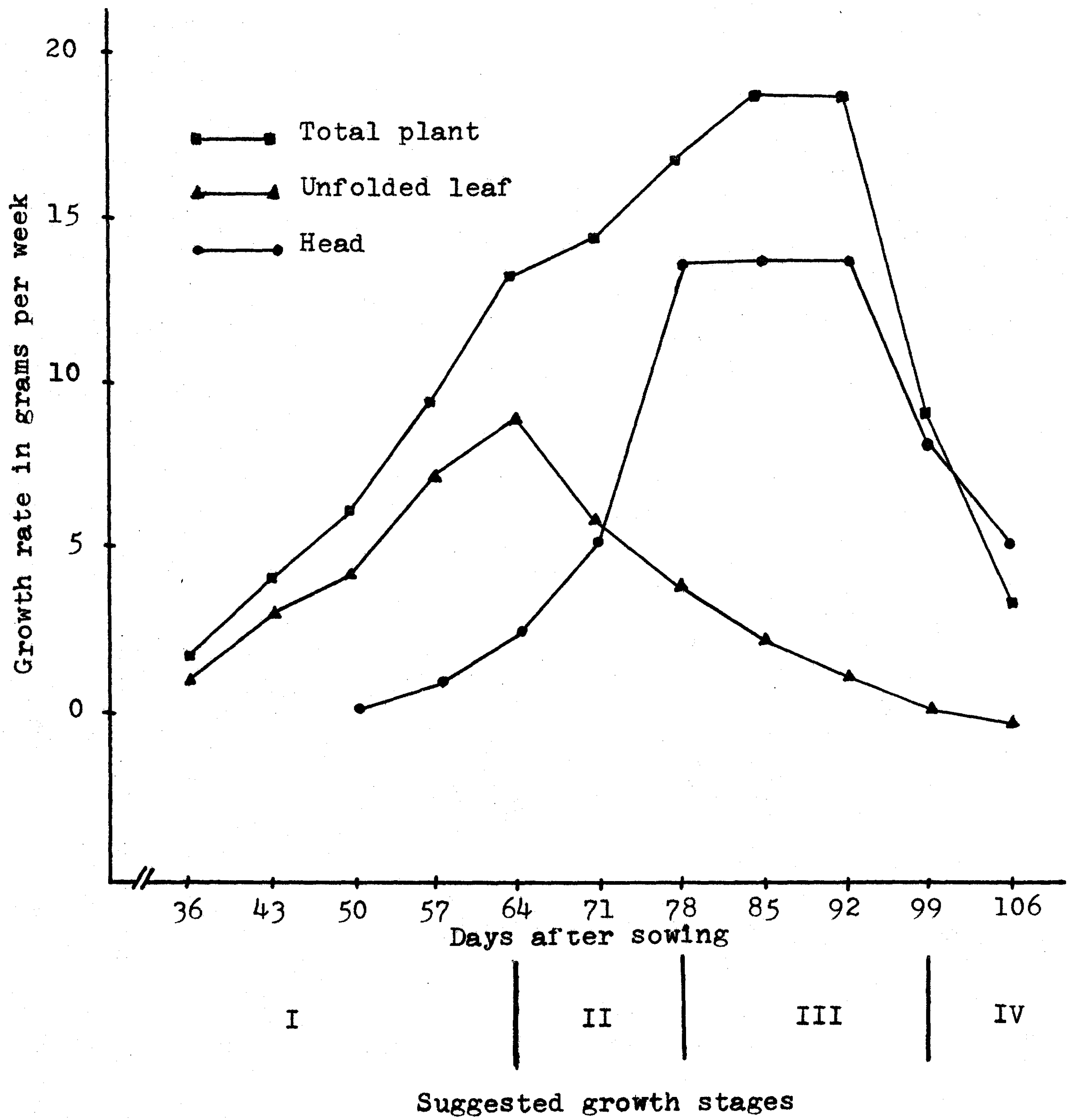

Figure 4 : Growth rates in grams of dry weight per week of the total plant and plant parts in the greenhouse, as well as the suggested growth stages. (Cabbage Trial C-1, summer 1969)

Table (4). Average Plant Transpiration in Grams of Water per Cabbage Plant and Environmental Records During Two-Hour Periods (6 a.m. to 10 p.m.) in the Greenhouse (Trial C-1)

Measurements and records	Time of day							
	6 a.m.to 8 a.m.	8 a.m.to 10 a.m.	10 a.m.to 12 noon	12 noon to 2 p.m.	2 p.m.to 4 p.m.	4 p.m.to 6 p.m.	6 p.m.to 8 p.m.	8 p.m.to 10 p.m.
Average transpiration	9.77	33.05	60.64	80.69	65.85	67.28	37.70	11.75
	** →	** →	** →	← **	N.S. →	← **	← **	
Average air temperature (F)	59.2	64.5	70.9	73.1	74.5	74.1	70.8	67.4
Average relative humidity (%)	80	77	65	61	58	59	61	62

N.S. non-significant difference * 5% level significance ** 1% level significance

observations in this experiment whether the high transpiration rate in the period of 12 noon to 2 p.m. was caused by a higher light intensity or whether there may have been slight wilting in the later afternoon periods (2 to 6 p.m.) which reduced the rate of transpiration.

The significant differences in transpiration in a 24-hour period under both greenhouse and growth chamber conditions, as well as the temperature records of the greenhouse on each day that measurements were taken,are presented in Table 5. The results of transpiration in the greenhouse were similar to those in the growth chamber, but transpiration per plant was higher under the greenhouse conditions except for one occasion when it was cloudy and raining (57 days in Table 5). It is obvious that the erratic pattern of transpiration in the greenhouse was caused by environmental changes while plants in the growth chamber were only affected by their growth stages. Transpiration in the growth chamber was found to increase rapidly up to 64 days, but no significant differences were found after that age had occurred.

According to these results, the maximum transpiration per plant occurred at the beginning of the switch over period between the proposed growth Stages I and II. Obviously, the decreases in the growth rate of the unfolded leaves and increases in the growth rate of the head stopped the increase in the transpiration per plant (Figures 1 and 2).

Table (5). Transpiration in Grams of Water per Cabbage Plant During a 24-Hour Period in the Greenhouse and the Growth Chamber, as well as the Temperature Records of the Greenhouse on the Day of the Trial (Trial C-1)

	Days after sowing										
Measurements	36	43	50	57	64	71	78	85	92	98	106
Transpiration (growth chamber)	34.0	127.4	181.7	254.9	356.2	347.1	359.8	336.8	343.3	329.8	317.4
		**	*	**	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Transpiration (greenhouse)	73.2	180.7	237.9	128.3	439.3	524.3	487.2	592.9	737.2	467.9	372.9
		**	N.S.	**	**	*	N.S.	**	**	**	**
Maximum day temperature (°F)	83	80	74	68	76	78	80	84	74	75	79
Minimum day temperature (°F)	62	57	57	57	52	54	58	64	62	67	61
Average day temperature (°F)	67.3	69.0	66.3	59.1	63.0	67.1	70.1	69.3	66.6	66.6	66.9

N.S. non-significant difference * 5% level significance ** 1% level significance

Plant growth-transpiration regression studies

It is obvious in Figures 1 and 2 (pages 53 and 54) that the pattern of the transpiration in the growth chamber coincided with the growth pattern of the unfolded leaves during the whole growing period, but the pattern of the transpiration only coincided with the growth pattern of the total plant up to 64 days after sowing. The results in these two figures also showed that transpiration started to level off when the head started to form. The studies of growth rates (Figures 3 and 4) also showed that there was a maximum weekly rate of increase in both the fresh and dry weights of the unfolded leaves before 64 days, while the maximum weekly rate of increase in both the fresh and the dry weights of the total plant and the head occurred later.

A summary of the regression studies on Trial C-1 is presented in Table 6. Although a good correlation between total fresh or dry weight of the plant and transpiration was obtained, it is obvious from the lack of correlation and previous discussion that head growth did not cause the increase in plant transpiration. Transpiration, however, was significantly correlated to the growth of the unfolded leaves when the transpiration measurements were conducted in both the growth chamber or the greenhouse.

Transpiration rate per gram of the plant weight

According to the regression studies, the trans-

Table (6). Summary of Plant Growth-Transpiration Regression Significance and Correlation Coefficients for Cabbage Plants (Trial C-1)

Measurements	Greenhouse	Growth chamber
Total fresh weight of the plant	** (0.75)	* (0.71)
Total dry weight of the plant	* (0.70)	* (0.69)
Fresh weight of the unfolded leaves	** (0.92)	** (0.93)
Dry weight of the unfolded leaves	** (0.87)	**(0.89)
Fresh weight of the head	N.S.(0.05)	N.S.(0.07)
Dry weight of the head	N.S.(0.04)	N.S.(0.06)

N.S. no significant difference * 5% level significance

** 1% level significance

piration per plant in a 24-hour period was found to correlate to the total plant and the unfolded leaf weights. Thus, the transpiration rates per gram of plant weight were only considered for these two measurements. The results for these measurements are presented in Table 7 and Figure 5. The maximum rate was found at 43 days after sowing in all the different measurements. The significant increases in these transpiration rates were due to a significant increase in the transpiration per plant at the time when there were non-significant increases in the plant weights (i.e. from 36 to 43 days). On the other hand, rapid increases in plant weight, or perhaps decreases in plant surfaces per unit of plant weight, caused a decrease in the transpiration rate per gram of plant weight after 43 days.

Estimated total water usage

The results of the average transpiration per plant in the various stages of growth have been discussed in a previous section, but the increase in water content of the plant has not been considered. Because the amount of water for the requirement of photosynthesis was very small, it has been ignored in these results. The results of the estimated water usage (sum of transpiration and water retained within plant tissue)by cabbage plants in the growth chamber are presented in Table 8.

Table (7). Transpiration Rates in Grams of Water per Gram of Cabbage Plant Tissue During a 24-Hour Period in the Growth Chamber (Trial C-1)

	Days after sowing																				
Measurements	36		43		50		57		64		71		78		85		92		98		106
Total fresh weight of the plant	2.03	**	2.70	**	1.47	**	1.05	N.S.	0.89	*	0.58	N.S.	0.47	N.S.	0.33	N.S.	0.27	N.S.	0.24	N.S.	0.23
Total dry weight of the plant	30.19	**	37.74	**	19.98	**	16.26	**	11.64	**	8.06	N.S.	6.52	N.S.	4.56	N.S.	3.75	N.S.	2.99	N.S.	2.73
Fresh weight of the unfolded leaves	2.27	**	2.96	**	1.64	**	1.21	N.S.	1.09	*	0.78	N.S.	0.87	N.S.	0.75	N.S.	0.68	N.S.	0.75	N.S.	0.88
Dry weight of the unfolded leaves	33.70	**	42.65	**	22.93	*	19.40	**	14.68	*	11.27	N.S.	11.68	N.S.	10.05	N.S.	8.96	N.S.	8.18	N.S.	8.71

N.S. no significant difference

* 5% level significance

** 1% level significance

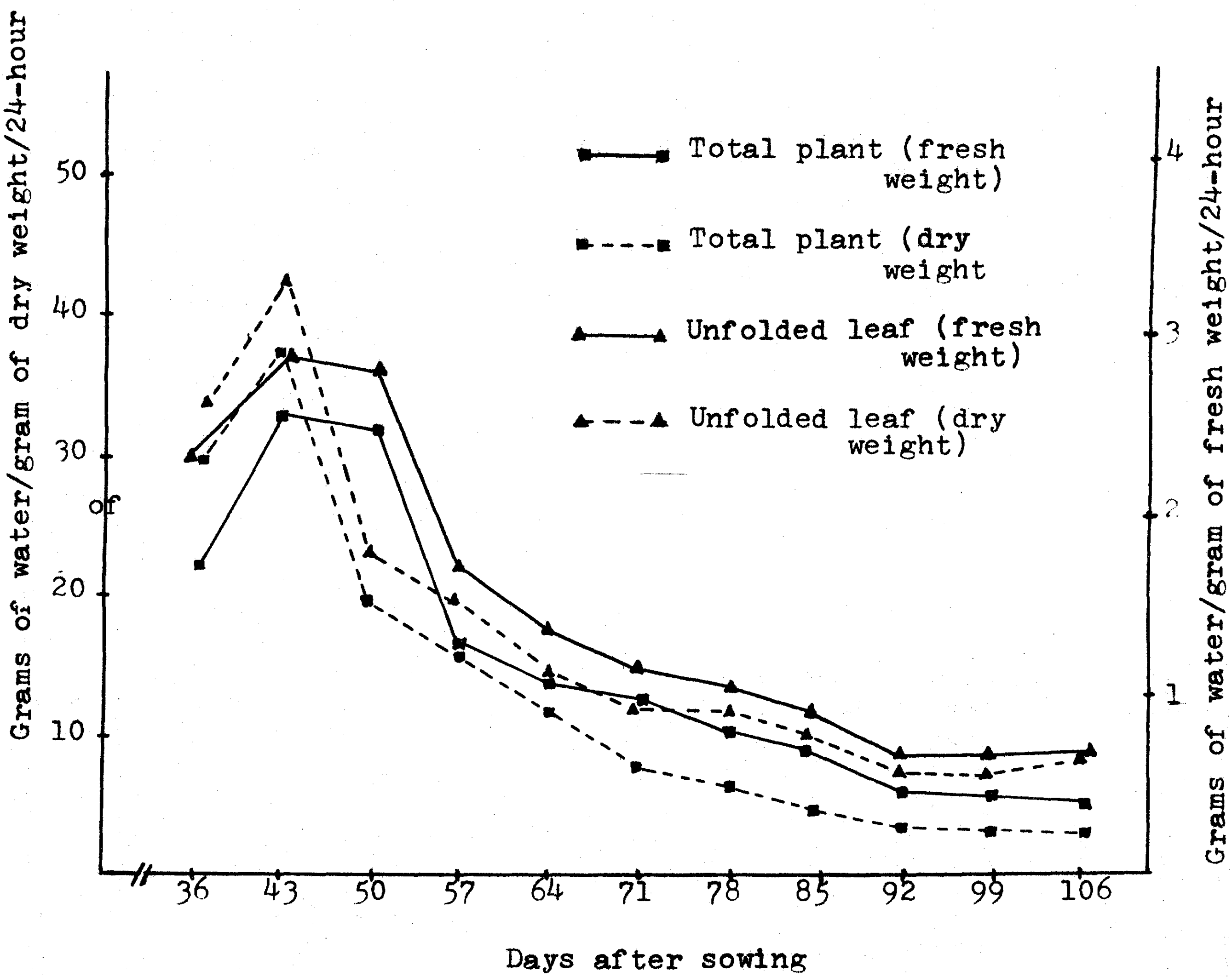

Figure 5 : Transpiration rates in grams of water per gram of plant weight in a 24-hour period in the growth chamber. (Cabbage Trial C-1, summer)

Table (8). Estimated Water Usage by Cabbage Plants in Gallons of Water per Day per Acre (Trial C-1)

Plant age in days	Average plant transpiration in the growth chamber	Water retained within plant tissue	Estimated total water usage
36 to 43	235 (2198)	12 (112)	247 (2310)
43 to 50	450 (4209)	30 (281)	480 (4490)
50 to 57	636 (5949)	47 (440)	683 (6389)
57 to 64	891 (8334)	60 (565)	951 (8895)
64 to 71	1025 (9587)	79 (739)	1104 (10326)
71 to 78	1030 (9634)	62 (580)	1092 (10214)
78 to 85	1015 (9494)	98 (917)	1113 (10411)
85 to 92	991 (9270)	101 (945)	1092 (10215)
92 to 99	981 (9176)	46 (430)	1027 (9606)
99 to 106	943 (8820)	- 9 (-84)	934 (8736)

Note : 11,000 plants per acre (15" spacing x 34" row width)

( ) indicate liters/day/hectare

The increases in the retained water of the plant in the earlier growing period were rather smaller than those in the middle or later period. The results showed that the increases in retained water of the plant from 78 to 92 days were about 10 per cent of the plant transpiration in the growth chamber.

According to the results (Table 8), the estimated total water usage showed a rapid increase up to the age from 64 to 71 days after sowing and then started to level off. The maximum estimated water usage in the growth chamber was 1113 gallons per day per acre. Even though the evaporative cooling system had been used during the transpiration measurement in the greenhouse, the environmental conditions were different on each day (Table 5) that data were calculated. Therefore, in the greenhouse trials transpiration showed a very erratic pattern depending upon climatic conditions. Calculated values of gallons per day per acre are not presented for this trial, but the highest water usage was estimated at 2148 gallons per day per acre for transpiration alone.

Cabbage Trial C-2

Plant growth and development

The plant materials for this trial were grown in the field during the summer of 1969. A summary of the average growth and plant transpiration is presented in Table 9, while a summary of the growth rates from this trial is presented in Table 10. According to the results in Table 9, the pattern of plant growth in the field was similar to the greenhouse trial. It is obvious that there were significant increases in the fresh weight of the total plant with the increments of plant age from 52 to 94 days. With the total dry weight of the plant, the increases occurred during the same period of time. The maximum weekly rate of increase in the total fresh weight (Table 10) was found from 66 to 80 days, while the maximum weekly rate of increase in the total dry weight was found at 73 days after sowing. Actually, the higher weekly rate of increase of the total fresh and dry weights occurred within the same growing period and the delay in significant dry weight increase found in the greenhouse was not apparent in the field. These results are probably due to lower temperature and higher transpiration per plant in the field as compared to the previous trial in the greenhouse (C-1).

With one exception for the period of 52 to 59 days, significant increases in the fresh weight of the unfolded leaves (Table 9) were found from 45 to 80 days and non-significant decreases were found after 80 days. Dry weight increases were found up to 87 days, but the increases were non-significant during the last two weeks of this period. The non-significant decreases found after 87 days were probably due to the loss of leaves through senescence.

Table (9). Average Weights, Measurements and Transpiration per Plant in a 24-Hour Period, as well as a Summary of Significance from Analysis of Variance Studies on Cabbage Plants (Trial C-2)

Measurements	Days after sowing 45		52		59		66		73		80		87		94		101
Total fresh weight of the plant (gm)	20.9	N.S.	73.1	*	188.2	**	332.1	**	457.3	*	642.3	*	732.0	**	873.5	N.S.	834.7
Total dry weight of the plant (gm)	2.3	N.S.	6.3	**	18.8	**	36.4	**	54.7	**	78.6	N.S.	85.8	**	100.1	N.S.	101.0
Fresh weight of the unfolded leaves (gm)	17.7	*	64.3	N.S.	104.1	**	285.1	*	341.2	*	404.6	N.S.	368.8	N.S.	357.0	N.S.	340.9
Dry weight of the unfolded leaves (gm)	1.9	N.S.	5.4	*	16.1	**	30.8	*	41.3	N.S.	47.5	N.S.	55.5	N.S.	50.0	N.S.	49.6
Fresh weight of the head (gm)	-		0.6	N.S.	3.0	N.S.	11.5	N.S.	67.8	*	205.5	N.S.	265.8	**	442.5	N.S.	419.9
Dry weight of the head (gm)	-		0.04	N.S.	0.30	N.S.	1.15	N.S.	6.24	**	18.27	N.S.	21.0	**	36.6	N.S.	35.7
Equatorial diameter of the head (cm)			0.8	N.S.	1.7	*	3.0	**	5.5	**	8.2	N.S.	9.4	N.S.	10.2	N.S.	10.3
Polar diameter of the head (cm)	-		2.1	N.S.	3.2	N.S.	4.1	**	6.6	**	9.0	N.S.	10.0	N.S.	10.2	N.S.	11.1
Transpiration (gm of water/plant/24-hour)	62.0	*	184.4	**	794.4	**	631.8	**	776.4	N.S.	706.0	N.S.	677.0	*	576.2	N.S.	541.0

N.S. non-significant difference * 5% level significance ** 1% level significance

Table (10). The Growth Rates per Week of the Total Plant and Selected Plant Parts at the Different Ages of Cabbage Plants (Trial C-2)

	Days after sowing								
Measurements	45	52	59	66	73	80	87	94	101
Total fresh weight of the plant (gm)	15.0	70.0	123.0	145.0	145.0	145.0	102.0	51.0	8.0
Total dry weight of the plant (gm)	2.0	7.4	12.8	18.6	22.4	16.2	10.6	3.6	0.4
Fresh weight of the unfolded leaves (gm)	13.0	50.0	97.0	108.0	55.0	10.0	-12.0	-22.0	-32.0
Dry weight of the unfolded leaves (gm)	1.0	6.8	10.2	14.0	10.6	5.2	1.2	-2.0	- 5.4
Fresh weight of the head (gm)	-	1.0	2.0	32.0	66.0	96.0	120.0	85.0	10.0
Dry weight of the head (gm)	-	0.2	1.0	2.4	5.8	8.9	9.5	6.1	1.6
Equatorial diameter of the head (cm)	-	0.5	1.0	2.3	2.7	1.7	1.0	0.4	0.1
Polar diameter of the head (cm)	-	0.5	0.9	1.8	2.5	1.4	0.9	0.5	0.2

The maximum weekly rates of increase in both fresh and dry weight of the unfolded leaves (Table 10) were found at the same age (66 days after sowing).

The head (Table 9) was found to have non-significant increases in both fresh and dry weights from 52 to 73 days. With fresh and dry weights significant increases were only found during two periods, namely, 73 to 80 and 87 to 94 days. The maximum weekly rates of increase in both fresh and dry weights of the head (Table 10) were also found at the same age (87 days after sowing). Although the maximum weekly rate of increase in weights of the head was at 87 days, the maximum weekly rates of increase in both equatorial and polar diameters were found to be 14 days earlier, namely, at 73 days after sowing.

The growth of the unfolded leaves,as shown in Figures 6 and 7, constituted the greatest portion of the total plant growth until the start of head formation. Once head formation occurred the head growth contributed the greatest to further increases of the total plant weight.

The four growth stages in this trial (Figures 8 and 9) were similar to the previous trial in the greenhouse (C-1), but the periods were somewhat different. They were :

I. The unfolded leaf growth stage (up to 66 days after sowing);

II. The transition or the head formation stage (66 to 80 days after sowing);

III. The storage or the head enlargement stage (80 to 94

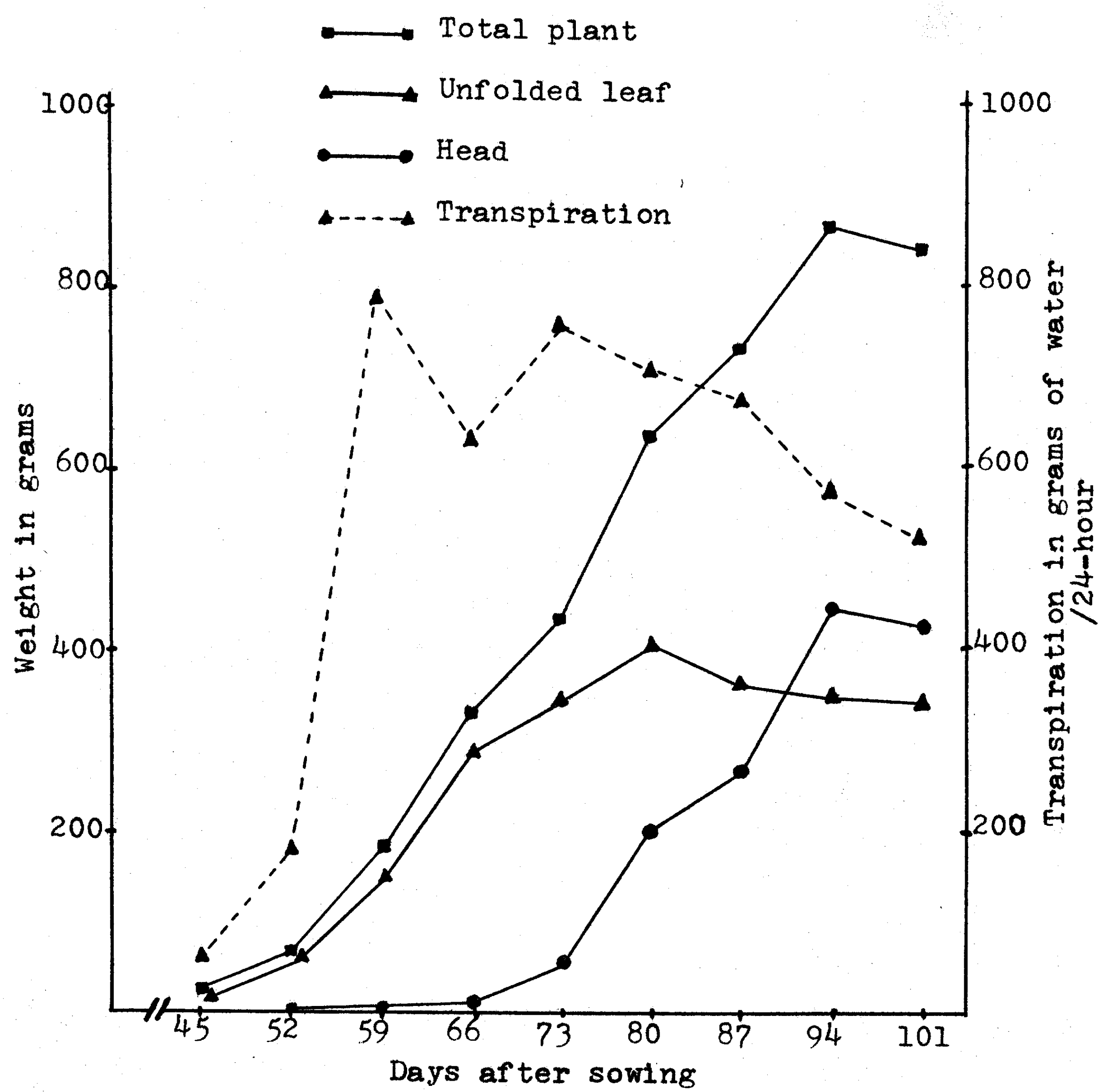

Figure 6 : Fresh weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the field, at different ages. (Cabbage Trial C-2, summer 1969)

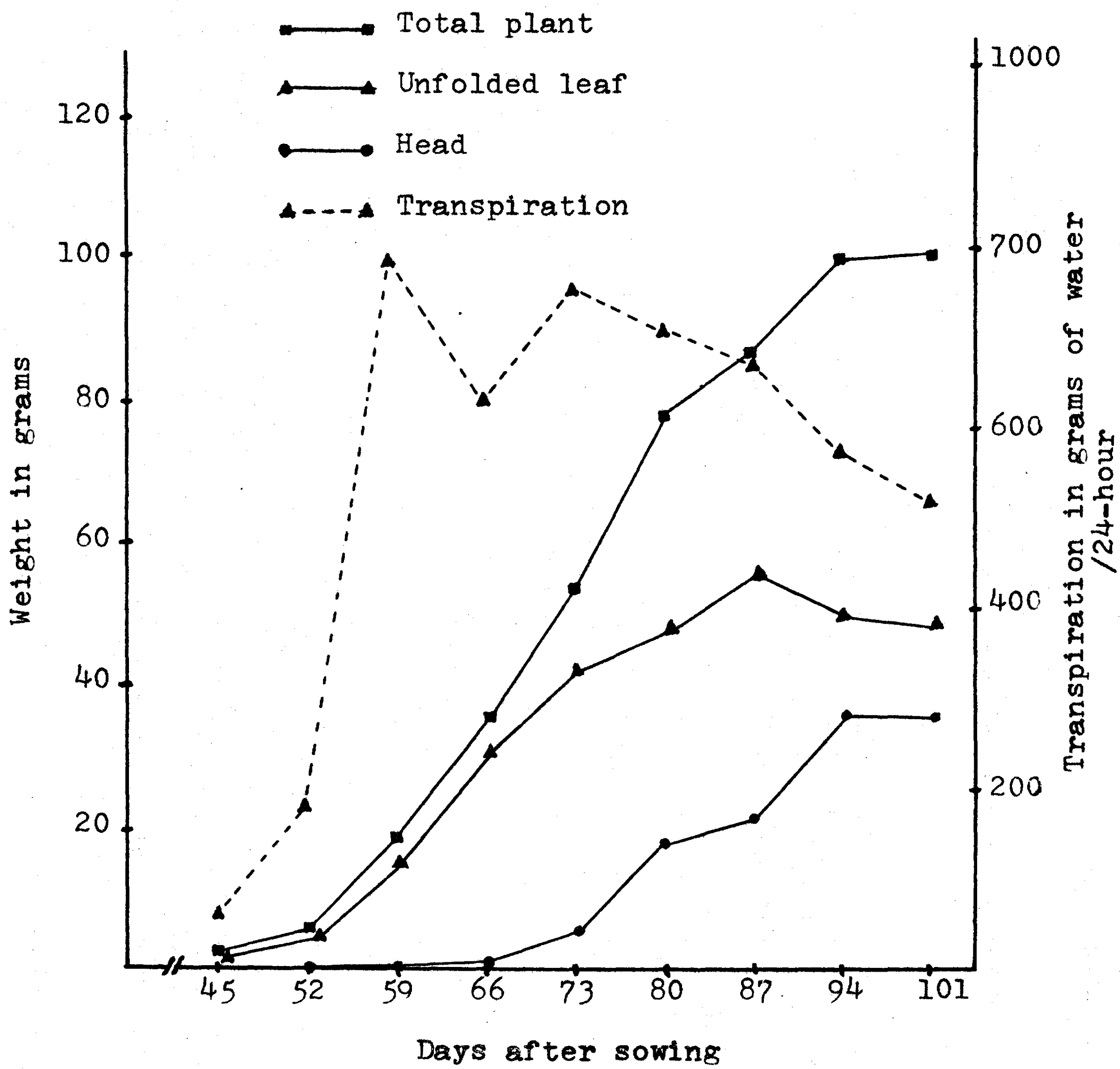

Figure 7 : Dry weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the field, at different ages. (Cabbage Trial C-2, summer 1969)

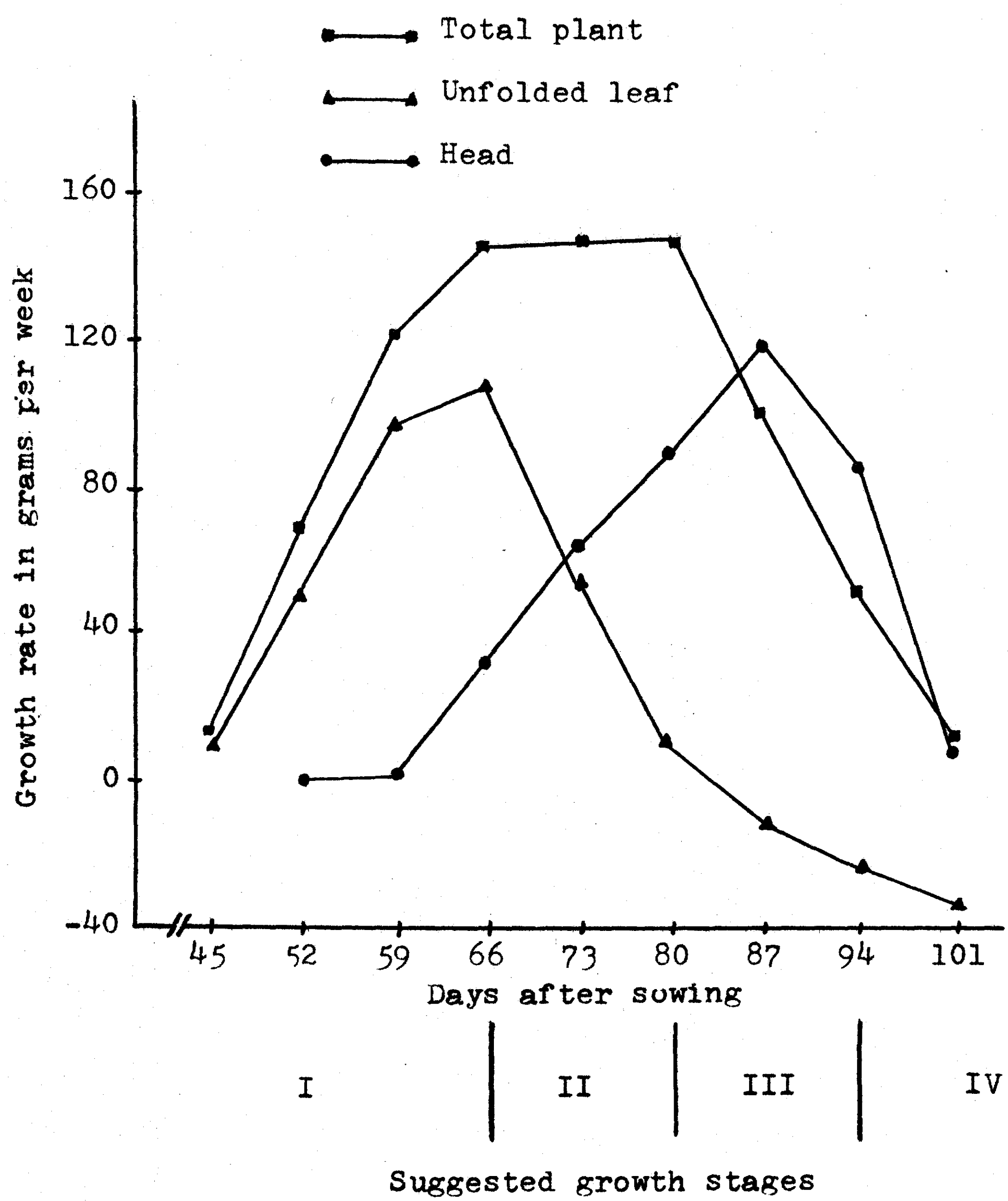

Figure 8 : Growth rates in grams of fresh weight per week of the total plant and plant parts in the field, as well as the suggested growth stages. (Cabbage Trial C-2, summer 1969)

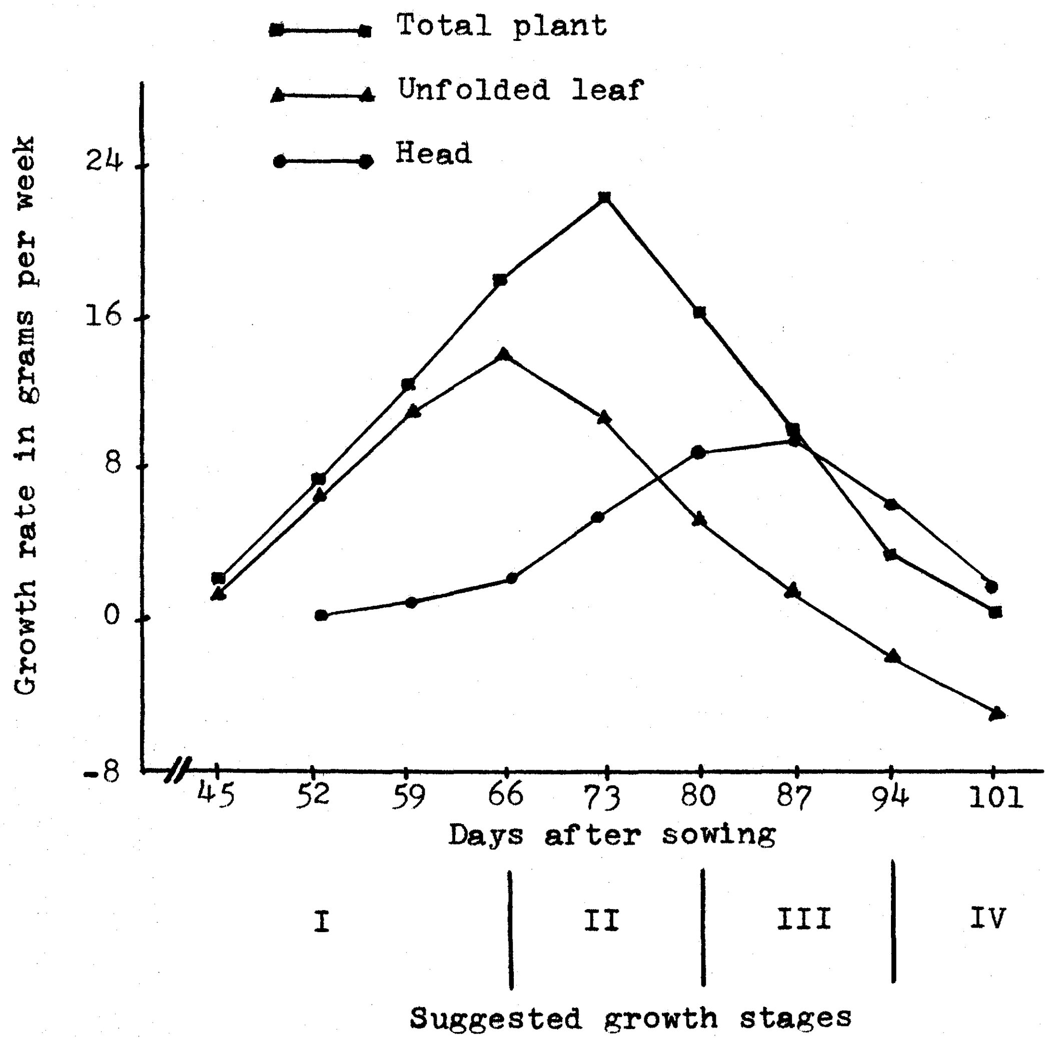

Figure 9 : Growth rates in grams of dry weight per week of the total plant and plant parts in the field, as well as the suggested growth stages. (Cabbage Trial C-2, summer 1969)

days after sowing); and

IV. The head maturity or the plant senescence stage (after 94 days).

Although significant increases in the different stages were similar to the last greenhouse cabbage trial (C-1), the plant age where the maximum growth rates in the fresh and dry weight in all measurements coincided, and the maximum rate of increase in the weights of the total plant was found entirely in the Stage II. This growth pattern would appear to be caused by the earlier development of dry matter and the fact that the heads were considerably smaller and did not contribute as much to the total weight as they did in the greenhouse.

Plant transpiration

The results of plant transpiration in the field showed a much more erratic pattern (Table 9, Figures 6 and 7) than was shown in the growth chamber. This could have been caused by many environmental factors which affected the results. Transpiration increased rapidly in the early growth stages with maximum transpiration occurring at the age of 59 days. It is obvious that climatic conditions (Table 11) affected the marked increase in transpiration between 52 and 59 days, particularly the difference in temperature and duration of sunshine. The significant decrease between 59 and 66 days must have been primarily due to the lower temperature and reduced wind speed even though the duration

Table (11). A Summary of Weather Records* During Transpiration Measurements Conducted in the Field (Trial C-2)

Plant age	Air temperature (°F)			Lowest	Max. wind speed	Duration of bright sunshine
	Max.	Min.	Mean	R.H.%	m.p.h.	hrs./day
45	73	38	55.5	26	21	11.1
52	62	51	56.5	46	19	3.4
59	85	50	67.1	43	22	11.6
66	74	47	60.1	43	16	14.3
73	80	57	68.1	26	20	14.9
80	84	55	69.1	42	20	13.8
87	81	55	66.0	30	20	8.5
94	63	39	51.0	28	27	3.8
101	85	59	70.2	34	16	13.7

* records from Saskatoon Airport Weather Office

of sunshine was longer. The increased temperature and wind speed, as well as reduced relative humidity at 73 days obviously was responsible for the transpiration increasing significantly again. It is fairly obvious that the older plants did not respond as much to environmental change. Although the conditions on the last two days were vastly different, there was no significant difference in transpiration. Because of higher day temperature, light intensity and wind speed in the field, the transpiration per plant was found to be much higher than that in the growth chamber.

Plant growth-transpiration regression studies

Although the growth pattern of the plant in the field was similar to the last trial in the greenhouse cabbage (C-1), the regression significances and the correlation coefficiences were somewhat different due to the erratic results of plant transpiration. Correlated with plant transpiration, they were as follows:

total fresh weight of the plant - N.S. (0.52),
total dry weight of the plant - N.S. (0.51),
fresh weight of the unfolded leaves - * (0.69),
dry weight of the unfolded leaves - * (0.67),
fresh weight of the head - * (-0.77), and
dry weight of the head - * (-0.77).

A good regression and positive correlation was only found between the leaf growth and plant transpiration.

A negative correlation was found between the head growth and plant transpiration. It is obvious that these results were probably due to the higher transpiration per plant which occurred in the early growing season while the head was just starting to form. The negative correlation between head formation and transpiration found in this trial, but not in the growth chamber or greenhouse, was probably due to poorer condition of the foliage and quicker decline in transpiration while the heads were growing in the field.

Estimated total water usage

The results of plant transpiration at the various stages of growth have been discussed in a previous section. Because the results of transpiration showed an erratic pattern, the estimated total water usage was only considered for the plant transpiration alone. Although the plant materials were smaller in this trial (101.0 grams total dry weight of the total plant in the field as compared to 116.6 grams in the greenhouse at maximum size), the transpiration per day per acre was greater than in the greenhouse. The maximum transpiration of 2315 gallons per day per acre can be expected to be a minimum amount of irrigation water needed to replace the water loss due to plant transpiration only.

Unfortunately, this trial under field conditions was not conducted by use of the lysimeter or the tent method, therefore, the evaporation from the soil surface should be taken into account for the total amount of irrigation water needed.

Cabbage Trial C-3

Plant growth and transpiration

The plant materials for this trial were grown in the growth chamber with controlled environmental conditions (60 degrees F night, 70 degrees F day and 2500 fc of light).

A summary of the average growth and transpiration per plant, as well as growth rates are presented in Table 12. The fresh weight of the total plant was found to significantly increase from 14 to 35 days, while significant increases in dry weight were from 21 to 35 days after sowing. The weekly increase rate in both the fresh and the dry weights of the total plant were found to increase continuously up to 35 days. Both fresh and dry weights at 35 days, however, were much smaller than from those at 36 days in the cabbage trial in the greenhouse (C-1). This was probably due to a lower temperature and lower light intensity.

Transpiration per plant in a 24-hour period was found to increase significantly from 14 to 35 days after sowing. It is obvious that this was due to the increase in the plant growth (i.e. from 2 cotyledons to 4 or 6 true leaves per plant). The regression studies between trans-

Table (12). **Average Weights, Growth Rates and Transpiration, as well as Significances from Analysis of Variance Studies on Cabbage Plants (Trial C-3).**

Measurements	Days after sowing 14	21	28	35
Fresh weight of the total plant (gm)	0.29	0.63	1.71	4.47
		*	**	**
Dry weight of the total plant (gm)	0.02	0.04	0.13	0.50
		N.S.	**	**
Growth rates in grams per week of the total plant (fresh weight)	0.18	0.32	2.00	2.75
Growth rates in grams per week of the total plant (dry weight)	0.01	0.04	0.17	0.75
Transpiration per plant in grams of water in a 24-hour period	0.84	2.52	6.49	14.49
		**	**	**

piration and plant growth showed that there was a high significant regression (1% level significance, r = 0.99) between the fresh weight of the total plant and transpiration, while only five per cent level significance (r = 0.98) with the dry weight was obtained.

This small trial was conducted because this early stage had not been recorded in the previous experiments. Obviously, transpiration increases from 14 to 35 days showed up significantly, however, the significant increases in this young plant stage would likely have been masked if the entire experiment from germination to maturity had been carried out.

Potato Trial P-1

Plant growth and development

The plant materials for this trial were grown in the greenhouse during the winter of 1968 and 1969. The average growth and a summary of its significance from the analysis of variance of the data of this trial are presented in Table 13, while the growth rates are presented in Table 14. The fresh weight of the total plant (Table 13) was found to increase significantly from 35 to 70 days, while the dry weight of the total plant was shown to increase

Table (13). Average Weights and Measurements, as well as a Summary of Significance from Analysis of Variance Studies on Potato Plants (Trial P-1)

Measurements	28	35	42	49	56	63	70	77	84
	Days after planting								
Total fresh weight of the plant (gm)	159.5	197.1	280.8	393.5	504.2	585.2	638.2	683.9	626.8
		N.S.	**	**	**	**	*	N.S.	*
Total dry weight of the plant (gm)	11.1	14.2	24.0	38.8	55.1	71.6	81.9	101.7	103.8
		N.S.	*	**	**	**	**	**	N.S.
Fresh weight of the leaves (gm)	82.7	100.9	140.5	161.8	174.0	174.1	172.6	148.9	66.8
		N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.	**
Dry weight of the leaves (gm)	6.7	8.0	11.8	13.2	14.1	14.7	14.3	13.4	11.3
		N.S.	**	*	N.S.	N.S.	N.S.	N.S.	N.S.
Fresh weight of tubers per plant (gm)	-	2.9	24.7	117.3	211.9	292.4	351.7	427.6	460.1
			N.S.	**	**	**	**	**	N.S.
Dry weight of tubers per plant (gm)	-	0.4	3.4	16.9	32.7	48.3	59.3	79.5	85.6
			N.S.	**	**	**	*	**	N.S.
Fresh weight of each tuber (gm)	-	1.3	3.2	12.5	20.3	30.7	33.8	34.1	34.0
			N.S.	**	**	**	N.S.	N.S.	N.S.
Dry weight of each tuber (gm)	-	0.18	0.44	1.79	3.13	5.06	5.69	6.35	6.36
			N.S.	*	*	**	N.S.	N.S.	N.S.
Equatorial diameter of the tuber (cm)	-	1.25	1.55	2.20	2.49	2.91	2.56	2.70	2.81
			*	**	*	**	*	N.S.	N.S.
Polar diameter of the tuber (cm)	-	1.41	1.80	2.84	3.33	3.89	3.40	3.44	3.57
			N.S.	**	*	*	*	N.S.	N.S.
Height of the stem (cm)	35.1	50.5	70.2	68.0	72.6	68.6	73.8	72.7	75.4
		**	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S. no significant difference   * 5% level significance   ** 1% level significance

Table (14). The Growth Rates per Week of the Total Plant and Selected Plant Parts at the Different Ages of Potato Plants (Trial P-1)

	Days after planting								
Measurements	28	35	42	49	56	63	70	77	84
Total fresh weight of the plant (gm)	42	67	98	125	93	63	43	8	-67
Total dry weight of the plant (gm)	3.0	7.0	9.5	12.4	15.3	17.3	19.3	13.3	2.0
Fresh weight of the leaves (gm)	20	30	28	18	7	0	-16	-37	-75
Dry weight of the leaves (gm)	1.2	3.0	2.2	1.1	0.5	0.2	-0.3	-1.1	-2.5
Fresh weight of tubers per plant (gm)	-	11	52	85	107	85	70	42	7
Dry weight of tubers per plant (gm)	-	2.0	6.3	11.0	15.6	18.0	15.0	11.3	3.3
Height of the stem (cm)	7.2	12.6	7.5	2.5	1.0	0.5	0.1	0	0

significantly from 35 to 77 days after planting. The maximum weekly rate of increase in the fresh weight of the total plant was found at 49 days and the maximum weekly rate of increase in the dry weight was found at 70 days after planting (Table 14). It is obvious that the dry matter of the potato plant was actively accumulating up to very near the end of the growth period. Plaisted (64) also showed that the accumulation was due to the great bulk from the tuber-filling activity. The significant decrease in the total fresh weight after 77 days was probably due to the tuber ripening and plant senescence.

A significant increase in the fresh weight of the leaves was found from 35 to 42 days (Table 13), while the significant increase in the dry weight was found from 35 to 49 days. Although both the fresh and dry weights increased up to 63 days, the increases were not significant in any one weekly period. Leaf senescence might be the most important reason for the significant decrease of the fresh weight of the leaves from 77 to 84 days. The slight decline in the dry weight was probably due to the loss of an occasional leaf. The maximum weekly rate of increase in both fresh and dry weights of the leaves (Table 14) was found at 35 days. Also, no increase or decline in the leaf growth was found after 63 days which was the age at which the maximum total leaf growth occurred.

The height of the stem (Table 13) was found to increase rapidly only before 42 days. Non-significant increases or decreases were found after that age. Also, the maximum weekly rate of increase in height of the stem (Table 14) was found at the same age as the maximum weekly rate of increase in the weights of the leaves.

Both fresh and dry weights of the tuber (Table 13) were found to increase significantly from 42 to 77 days. The maximum weekly rate of increase in the fresh tissue was found at 56 days, but the maximum weekly rate of increase in the dry weight was found at seven days later (i.e. 63 days). Although the total fresh and dry weights of tubers per plant increased significantly up to 77 days, the size of each tuber (fresh and dry weights, equatorial and polar diameters) was found to have non-significant differences after 63 days. From these results, it is obvious that the formation of small tubers continued over a period of time.

The growth patterns of the total plant and the plant parts (Figures 10 and 11) showed that the total plant growth was strongly related to the tuber growth after tuber formation.

According to the growth rate results (Table 14 and Figures 12 and 13), the total growing period of the potato plant can be arbitrarily divided into four periods. They were :

I. The young plant stage, only vegetative shoot growth and stolon initiation (up to 35 days);

II. The transition stage, also including stolon growth, as well as tuber setting (35 to 49 days) ;

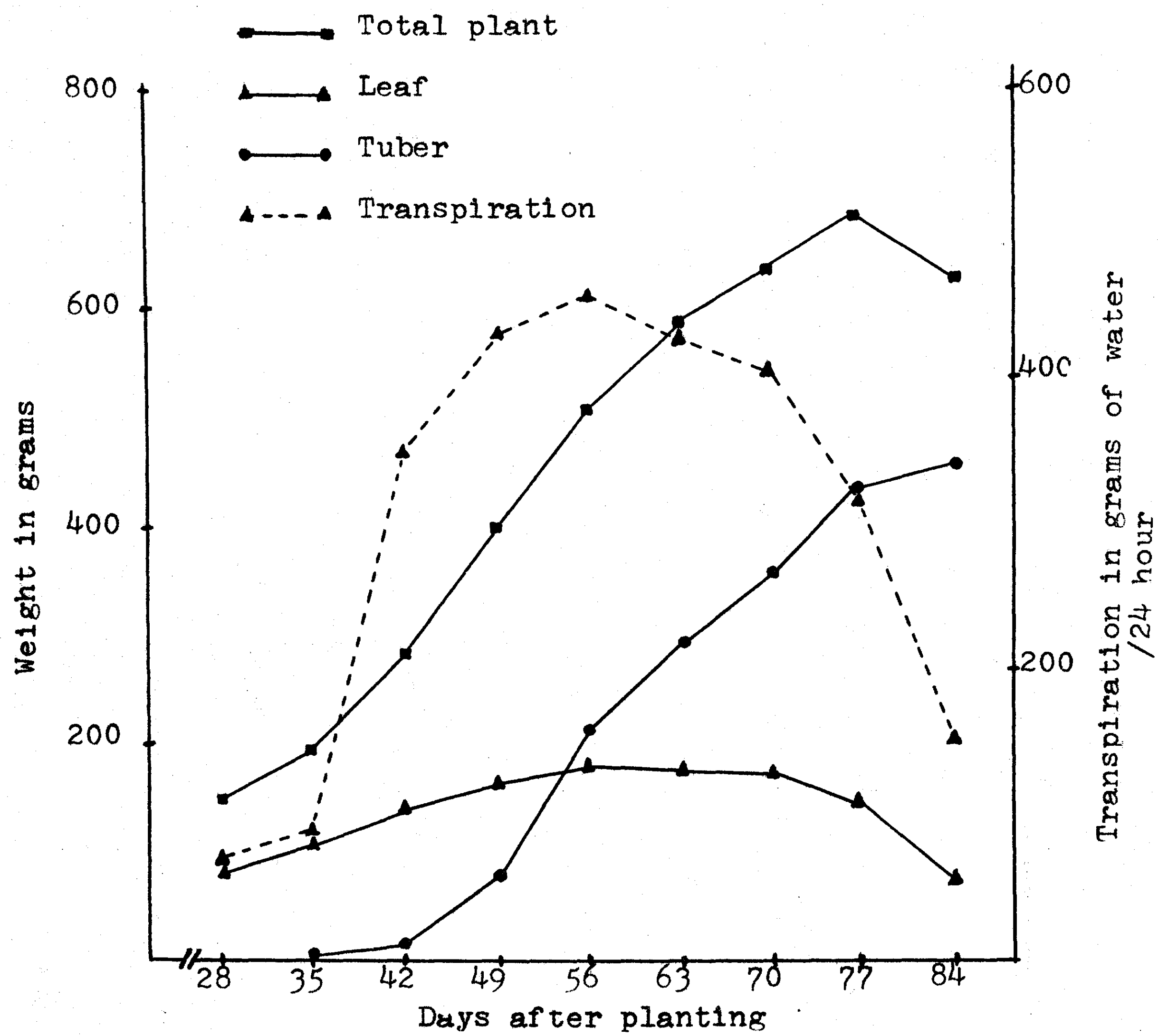

Figure 10 : Fresh weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the growth chamber, at different ages. (Potato Trial P-1, winter 1968-69)

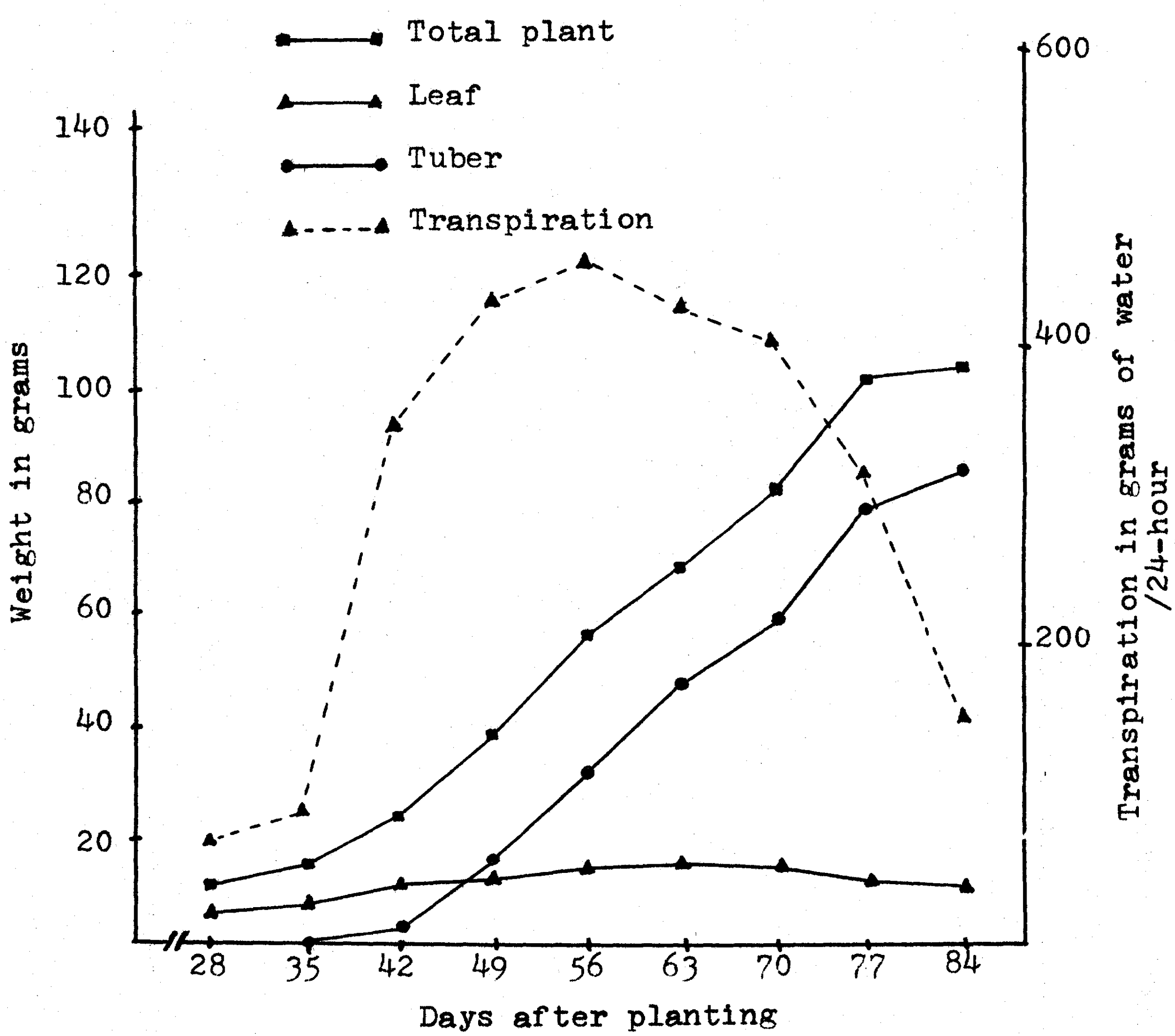

Figure 11 : Dry weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the growth chamber, at different ages. (Potato Trial P-1, winter 1968-69)

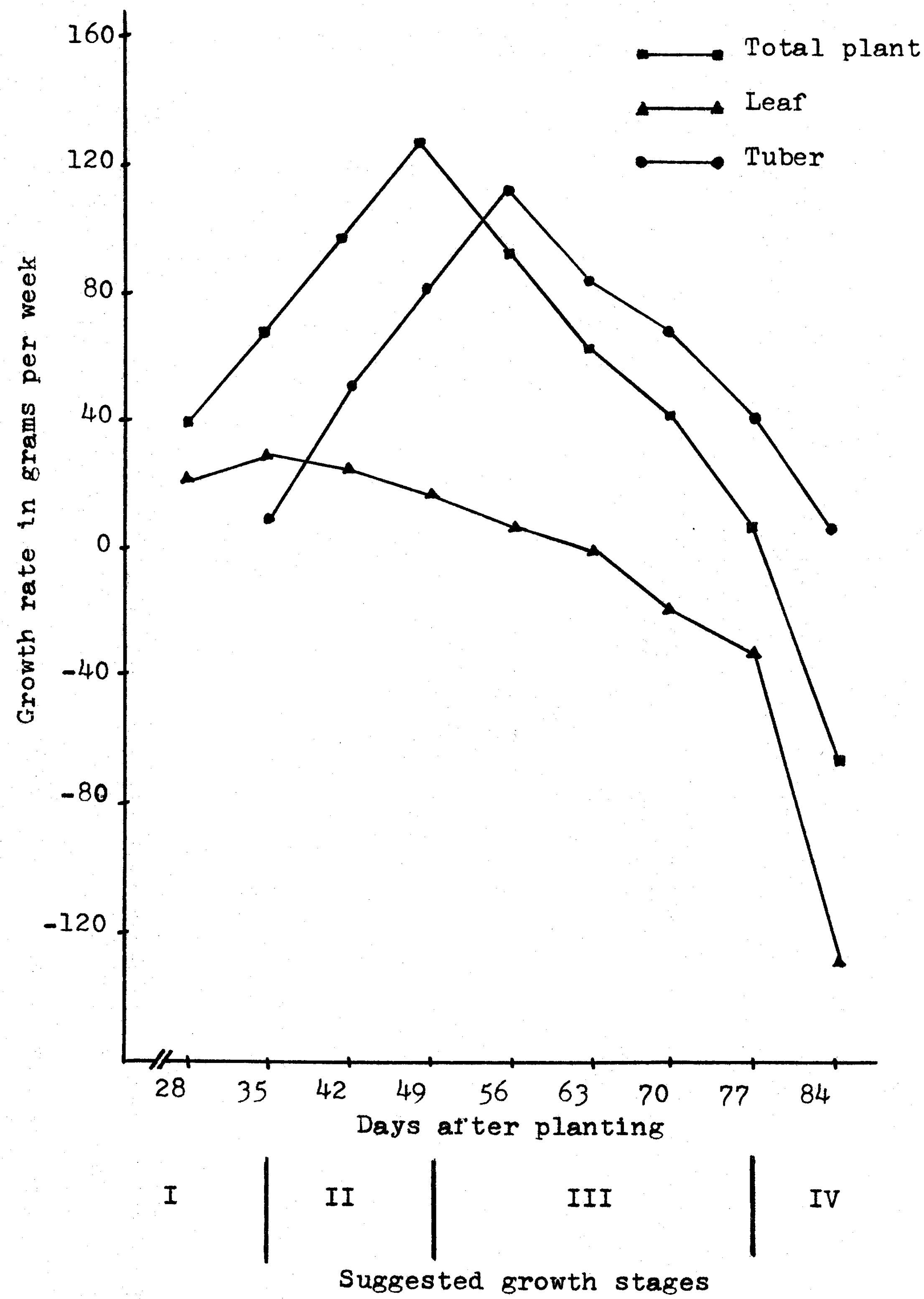

Figure 12 : Growth rates in grams of fresh weight per week of the total plant and plant parts in the greenhouse, as well as the suggested growth stages. (Potato Trial P-1, winter 1968-69)

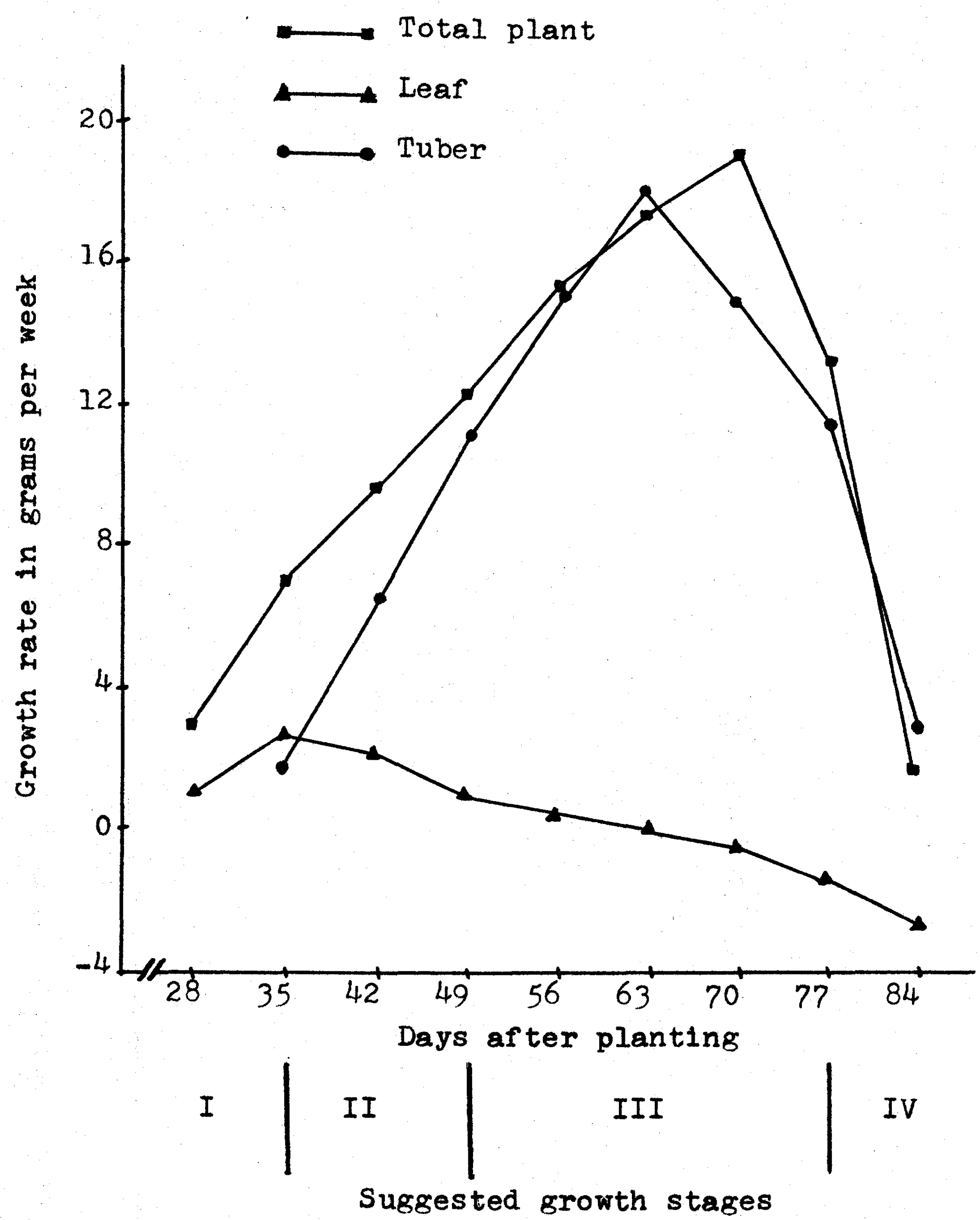

Figure 13 : Growth rates in grams of dry weight per week of the total plant and plant parts in the greenhouse, as well as the suggested growth stages. (Potato Trial P-1, winter 1968-69)

III. The maximum tuber growth stage (49 to 77 days); and

IV. The tuber ripening and plant senescence stage (after 77 days).

The rapid transition from shoot growth to tuber growth, according to these results, was found from 35 to 49 days although the physiological changes might have been induced in the tip of the stolon before 35 days. During this period, increases in the growth rate of the tuber and decreases in the growth rate of the shoot (leaves and stems) were also found (Figures 12 and 13). The decline in the leaf growth was found to coincide with the on-set of tuber formation. It was also stated by Leopold (44) that the time of tuber development was associated with a retarded growth of above-ground parts. According to the results (Figures 10 and 11), the maximum fresh weight of the total plant was found to be at the end of Stage III as shown in Figures 13 and 14. However, the total dry weight was found to increase up to the last harvest, but non-significantly. The marked decline in the fresh weight of the total plant and the maximum total tuber weight were the most important characteristics of the Stage IV.

Plant transpiration

The results of plant transpiration in a 24-hour period are presented in Table 15 and also shown in Figures 10 and 11. Rapid increases in transpiration per plant were

Table (15). Transpiration in Grams of Water per Potato Plant and Transpiration Rates in Grams of Water per Gram of Plant Tissue During a 24-Hour Period in the Growth Chamber (Trial P-1)

Measurements	Days after planting 28	35	42	49	56	63	70	77	84
Transpiration per plant	65.6	82.6	351.3	429.5	458.5	443.6	410.5	322.3	148.8
		N.S.	**	**	N.S.	N.S.	N.S.	**	**
Transpiration rate per gram of total fresh weight	0.41	0.42	1.25	1.10	0.91	0.76	0.65	0.48	0.24
		N.S.	**	**	**	**	*	**	**
Transpiration rate per gram of total dry weight	5.94	5.80	14.73	11.14	8.36	6.25	5.01	3.20	1.46
		N.S.	**	**	**	*	*	*	*
Transpiration rate per gram fresh weight of the leaves	0.79	0.82	2.49	2.67	2.64	2.55	2.38	2.17	2.23
		N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Transpiration rate per gram dry weight of the leaves	9.79	10.33	29.94	32.65	32.48	30.10	28.79	24.25	13.31
		N.S.	**	N.S.	N.S.	N.S.	N.S.	*	**

N.S. non-significant difference * 5% level significance ** 1% level significance

found from 35 to 49 days, but non-significant increases were found from 28 to 35 and 49 to 56 days after planting. Transpiration was also found to decrease after 56 days, but the decreases did not become significant until 70 days after planting. According to these results, the age for the higher transpiration per plant was very near to that age for the maximum total leaf and stem growth (Table 13 and Figures 10 and 11).

Plant growth-transpiration regression studies

The results of the regression significance test and correlation coefficiency between plant growth and transpiration per plant were as follows:

total fresh weight of the plant	- N.S.	(0.53),
total dry weight of the plant	- N.S.	(0.32),
fresh weight of the leaves	- **	(0.9),
dry weight of the leaves	- **	(0.93),
fresh weight of the tuber	- N.S.	(0.06), and
dry weight of the tuber	- N.S.	(-0.03).

According to these results, plant transpiration was only found to relate significantly to the fresh and dry weights of the leaves, while the total plant and tuber weights showed non-significant differences. The results also confirmed that the maximum transpiration was related to the maximum leaf growth.

Transpiration rates per gram of the plant weight

The results of the transpiration rates in grams of water per gram of plant weight, as well as of the plant parts, in a 24-hour period in the growth chamber are presented in Table 15 and Figure 14. The results showed that there were non-significant increases in the transpiration rate in all measurements from 28 to 35 days after planting. These results were probably due to the lack of a significant increase in both transpiration per plant and plant growth during the same period of time. The maximum transpiration rate per gram of total fresh and dry weights of the plant was found at 42 days. It was also shown that there was a continuous decrease in the transpiration rates per gram of the total plant weight after that plant age. The reason for this, perhaps, was due to rapid tuber growth which formed an increasing amount of the plant weight, but did not contribute to transpiration. The maximum transpiration rate per gram of leaf weight was found to be one week later than that of the total plant weight, i.e. 49 days. The decreases in transpiration rates per gram of leaves were rather more gradual than that of the total plant because the effect of increasing weight of the tuber was eliminated. Because the dry weight of the leaves decreased more gradually than the fresh weight, a significant decrease in transpiration rate per gram of dry weight of the leaves occurred after 77 days.

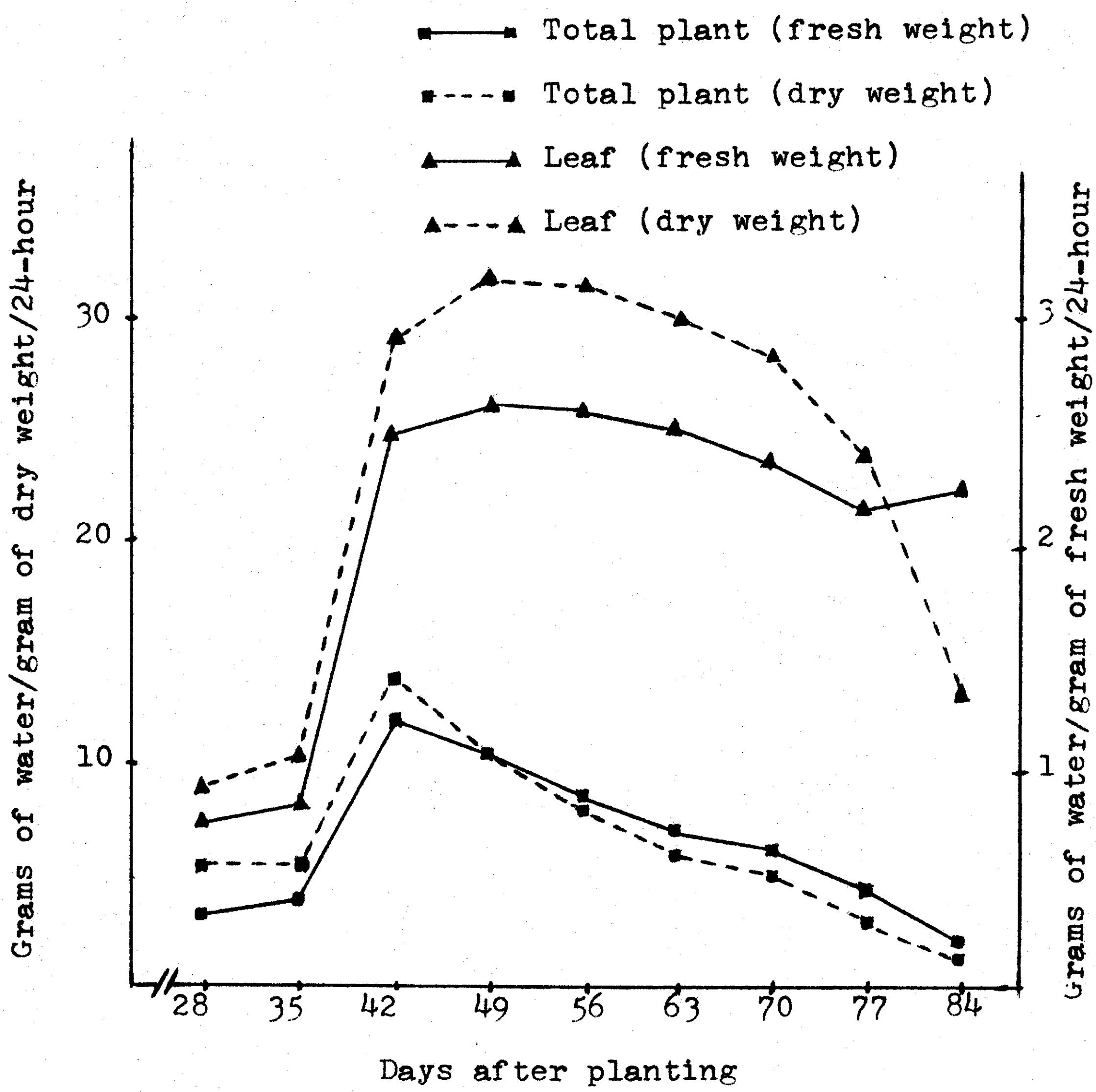

Figure 14: Transpiration rates in grams of water per gram of plant weight in a 24-hour period in the growth chamber. (Potato Trial P-1, winter 1968-69)

Estimated total water usage

Plant transpiration and the average increase in retained water of the plant were also taken into account for the total water usage in the potato trials. The results of the estimated water usage for this trial are presented in Table 16. The results showed that the higher increases in retained water from 42 to 56 days were found to be only about three to four per cent of the average transpiration in the growth chamber.

According to the results in Table 16, the estimated total water usage of plants was found to rapidly increase up to the period from 56 to 63 days and then started to level off. The maximum total estimated water usage, according to the growth chamber measurement, was 1909 gallons per day per acre, but it should be remembered that these were single-stemmed plants and the use of water would have been much greater with multiple-stemmed plants ordinarily used in cultivation.

Potato Trial P-2

Plant growth and development

The plant materials for this trial were grown in the greenhouse during the summer of 1969.

A summary of average growth and significant

Table (16). Estimated Water Usage by Potato Plants in Gallons of **Water** per Day per Acre (Trial P-1)

Plant ages in days	Average plant transpiration in the growth chamber	Water retained within plant tissue	Estimated total water usage
28 to 35	259 (2423)	17 (159)	276 (2582)
35 to 42	758 (7090)	37 (346)	795 (7436)
42 to 49	1365 (12768)	49 (458)	1414 (13226)
49 to 56	1552 (14517)	47 (440)	1599 (14957)
56 to 63	1577 (14751)	32 (299)	1609 (15050)
63 to 70	1493 (13965)	21 (196)	1514 (14161)
70 to 77	1281 (11982)	13 (122)	1294 (12104)
77 to 84	823 (7698)	-30 (-281)	793 (7417)

Note : 13200 plants per acre (14" spacing x 34" row width)

( ) indicate liters of water/day/hectare differences from the analysis of variance of the data of the potato trial P-2 are presented in Table 17, while the growth rates are presented in Table 18. The fresh weight of the total plant was found to increase significantly from 21 to 77 days and was also found to decrease rapidly from 84 to 91 days after planting. The growth pattern of the total dry weight was found to be similar to the fresh weight, except the dry weight was found to rapidly increase from 77 to 84 days and a non-significant decrease occurred from 84 to 91 days (Table 17). According to the results in Table 18, the maximum weekly rate of increase in the total fresh weight of the plant was found at 56 days, while that for the dry weight was found at 63 days after planting. The results of the previous potato trial in the greenhouse (P-1) showed the maximum weekly rate of increase in the dry weight of the total plant at 21 days later than it was in the fresh weight. This difference between these two trials was probably due to seasonal effects.

The fresh weight of the leaves was found to rapidly increase from 21 to 49 days, but there was a non-significant increase in each weekly measurement from 49 to 63 days. Although the decreases from 63 to 84 days were non-significant, a rapid decrease was found from 84 to 91 days after planting. The dry weight was found to increase significantly from 14 to 49 days, but there were found to be non-significant increases from 49 to 77 days. Significant decreases were found from 77 to 91 days (Table 17). The maximum

Table (17). Average Weights and Measurements, as well as a Summary of Significance from Analysis of Variance Studies on Potato Plants (Trial P-2)

Measurements	Days after planting 14	21	28	35	42	49	56	63	70	77	84	91
Total fresh wt. of the plant (gm)	14.8	47.3	143.2	251.0	405.5	545.6	634.6	780.8	917.7	997.0	1137.5	1020.6
		N.S.	**	**	**	**	**	**	**	**	N.S.	**
Total dry wt. of the plant (gm)	1.0	3.6	9.5	16.0	29.3	47.6	54.6	78.2	108.7	122.2	154.9	153.4
		N.S.	**	**	**	**	**	**	**	**	**	N.S.
Fresh wt. of the leaves (gm)	8.1	27.8	91.5	149.3	226.5	273.8	299.4	313.6	299.6	288.5	288.1	187.9
		N.S.	**	**	**	**	N.S.	N.S.	N.S.	N.S.	N.S.	**
Dry wt. of the leaves (gm)	0.6	2.6	6.8	10.8	18.1	24.7	24.6	26.7	26.2	25.6	24.0	22.2
		*	**	**	**	**	N.S.	N.S.	N.S.	N.S.	*	*
Fresh wt. of tubers per plant (gm)		-	-	-	-	38.8	104.2	243.8	408.3	504.2	619.1	635.1
							**	**	**	**	**	N.S.
Dry wt. of tubers per plant (gm)		-	-	-	-	4.7	12.5	33.2	66.1	82.5	110.1	115.8
							N.S.	**	**	**	**	N.S.
Fresh wt. of each tuber (gm)		-	-	-	-	3.03	7.08	17.62	19.26	27.94	33.01	39.22
							N.S.	**	N.S.	**	N.S.	*
Dry wt. of each tuber (gm)		-	-	-	-	0.37	0.85	2.40	3.12	4.60	5.86	7.16
							N.S.	**	N.S.	**	*	*
Equatorial diameter of the tuber (cm)		-	-	-	-	1.53	1.90	2.46	2.33	2.54	2.90	2.97
							**	**	N.S.	N.S.	**	N.S.
Polar diameter of the tuber (cm)		-	-	-	-	1.88	2.48	3.39	3.30	3.56	4.01	4.13
							**	**	N.S.	N.S.	*	N.S.
Height of the stem (cm)	7.5	19.0	38.1	54.3	75.5	90.1	99.8	102.7	93.7	97.9	105.1	98.4
		**	**	**	**	**	**	N.S.	N.S.	N.S.	N.S.	N.S.

N.S. no significant difference * 5% level significance ** 1% level significance

Table (18). The Growth Rates per Week of the Total Plant and Selected Plant Parts at the Different Ages of Potato Plants (Trial P-2)

	Days after planting											
Measurements	14	21	28	35	42	49	56	63	70	77	84	91
Total fresh wt. of the plant(gm)	16	50	75	105	145	165	166	135	100	70	22	-20
Total dry wt. of the plant(gm)	2.0	3.5	5.3	8.0	11.0	16.3	22.0	30.6	22.0	19.3	10.3	4.0
Fresh wt. of the leaves (gm)	10	36	51	68	65	38	19	8	-10	-20	-38	-75
Dry wt. of the leaves(gm)	1.5	3.1	4.2	5.5	4.6	3.6	2.3	1.3	0.7	-1.0	-2.3	-4.0
Fresh wt. of tubers per plant(gm)	-	-	-	-	-	50	80	125	165	115	60	20
Dry wt. of tubers per plant (gm)	-	-	-	-	-	6.3	10.6	17.0	30.6	25.3	10.7	4.0
Height of the stem (cm)	5.3	9.8	19.5	22.8	13.5	8.5	5.3	2.5	1.0	0.5	0	0

total growth of the leaves in both fresh and dry weights was found at 63 days. According to these results (Table 18), the weekly rates of increase in the leaves in both fresh and dry weights were found to increase up to 35 days, and then decreased.

The height of the stem was found to increase rapidly in the early growing period from 14 to 49 days (Table 17). The non-significant increases or decreases were found after 49 days. The maximum weekly rate of increase in the height of the stem was also found to coincide with the maximum weekly rate of increase in the weight of the leaves at 35 days after planting (Table 18).

Both the fresh and the dry weights of the tubers were found to increase significantly during nearly the whole tuber growing period, i.e. from 49 to 84 days for the fresh weight, and from 56 to 84 days for the dry weight (Table 17). Generally, the tuber was found to increase significantly in weight up to the last harvest, but both equatorial and polar diameters of each tuber were found to increase rapidly only in the early tuber growing period from 49 to 63 days. It is obvious that the tuber growth was similar to the head growth of cabbage, both of them tending to increase firstly in volume then in weight.

Because the growth measurements were taken earlier in this trial than in the previous trial in the greenhouse (P-1), the growth pattern of the total plant (Figures 15 and 16) seemed to show a closer relationship to the leaf growth

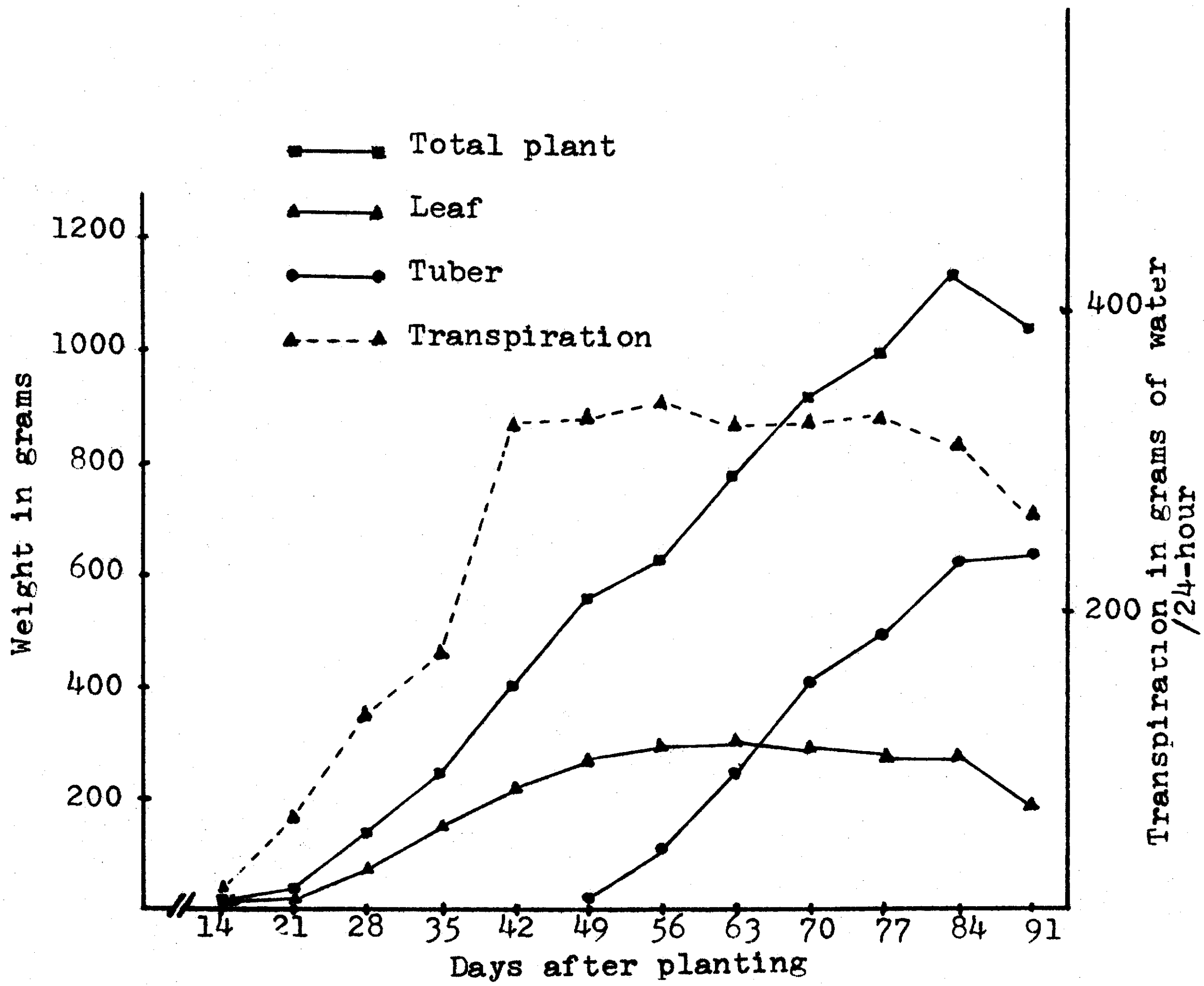

Figure 15 : Fresh weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the growth chamber, at different ages. (Potato Trial P-2, summer 1969)

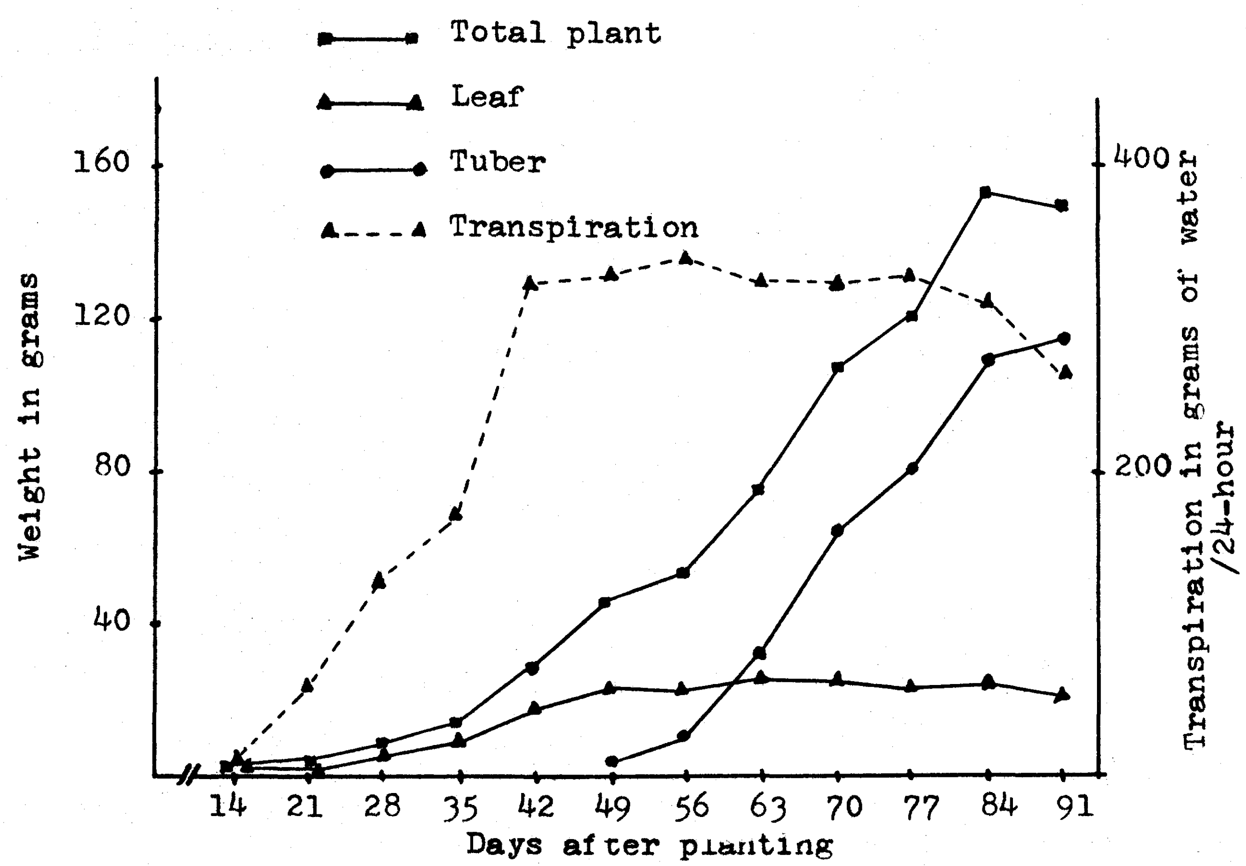

Figure 16 : Dry weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the growth chamber, at different ages. (Potato Trial P-2, summer 1969)

before tuber formation. However, it is also obvious that the total plant growth depended on the tuber growth after tuber formation.

According to these results (Table 18 and Figures 17 and 18), the author also arbitrarily divided the whole growing season into four stages. They were

I. The young plant stage (up to 49 days);

II. The transition stage (from 49 to 63 days);

III. The maximum tuber growth stage (from 63 to 84 days);and

IV. The tuber ripening and plant senescence stage (after 84 days).

The first stage in this trial was found to be 14 days longer than the potato trial in the greenhouse (P-1). This was probably due to the higher day temperature and longer photoperiod which were found by other researchers (7, 28,44,67) to inhibit tuber formation and thus, delayed the start of the Stage II. The plant started to flower at the same age as in the previous trial (42 days after planting), but in this trial tuber formation was seven days later and did not coincide with flowering.

Plant transpiration

A summary of plant transpiration in every two-hour period of the day from 6 a.m. to 10 p.m. and the environmental record are presented in Table 19. The maximum transpiration per plant in these results was found during

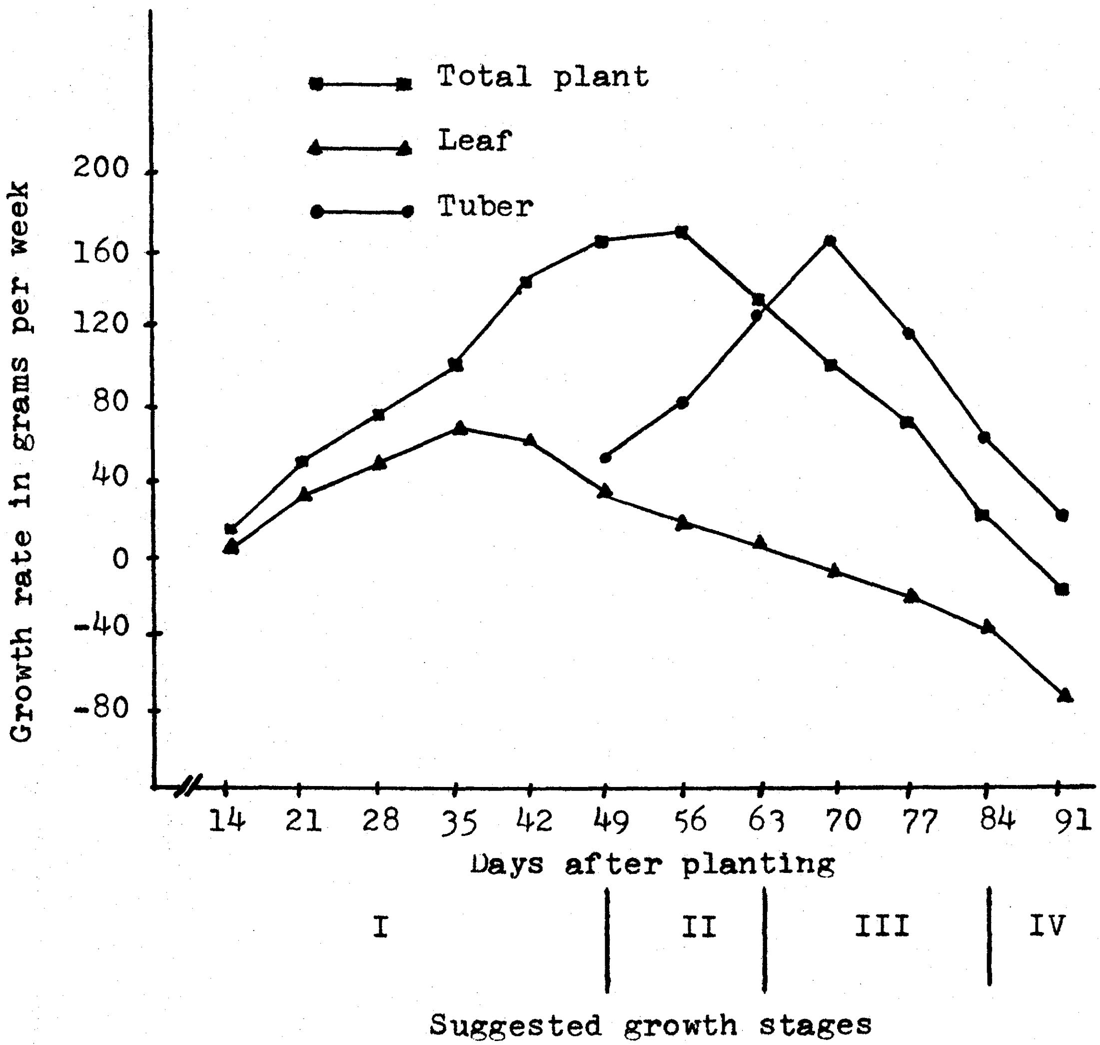

Figure 17 : Growth rates in grams of fresh weight per week of the total plant and plant parts in the greenhouse, as well as the suggested growth stages. (Potato Trial P-2, summer 1969)

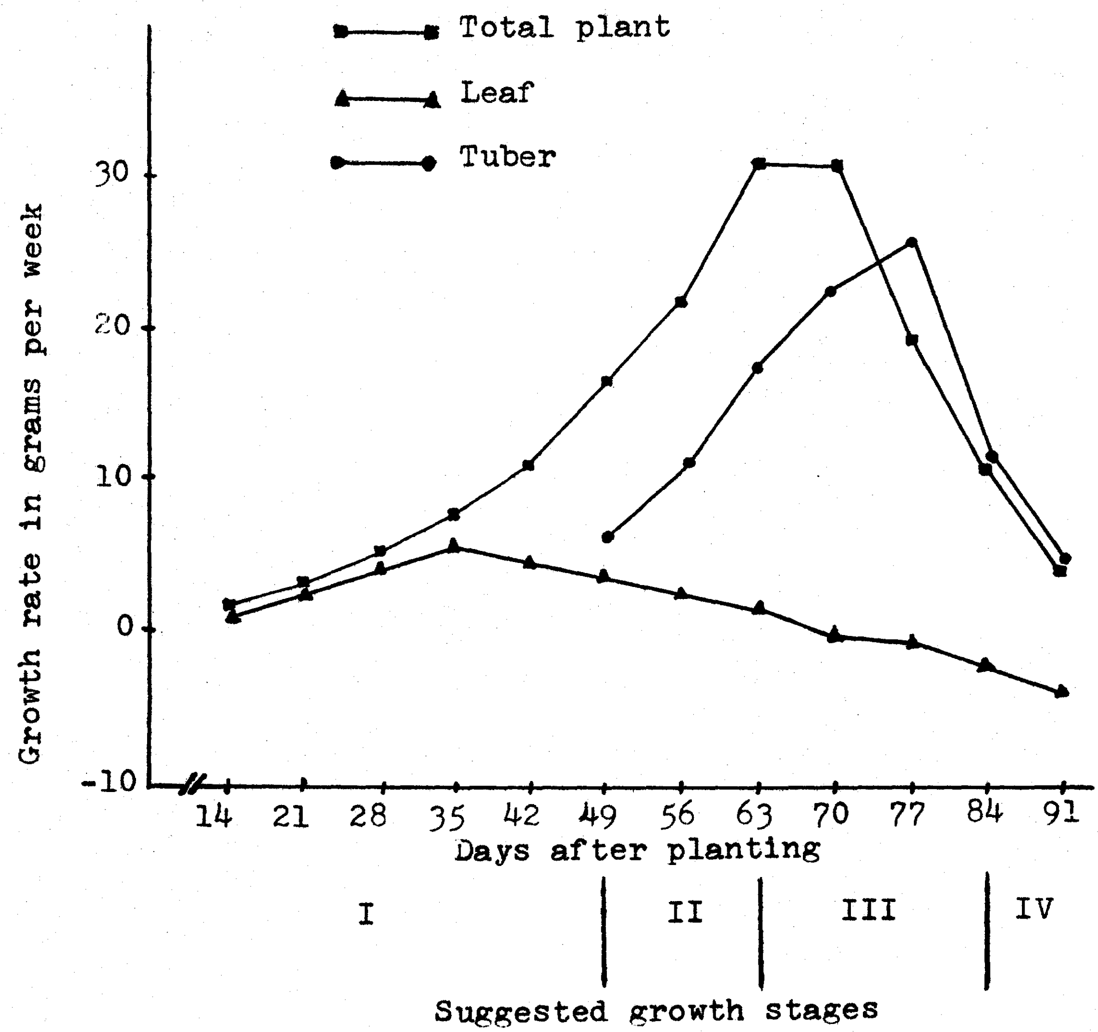

Figure 18 : Growth rates in grams of dry weight per week of the total plant and plant parts in the greenhouse, as well as the suggested growth stages. (Potato Trial P-2, summer 1969)

Table (19). Average Plant Transpiration in Grams of Water per Potato Plant and Environmental Records During Two-Hour Periods (6 a.m. to 10 p.m.) in the Greenhouse (Trial P-2)

Measurements and records	Time of day							
	6 a.m. to 8 a.m.	8 a.m. to 10 a.m.	10 a.m. to 12 noon	12 noon to 2 p.m.	2 p.m. to 4 p.m.	4 p.m. to 6 p.m.	6 p.m. to 8 p.m.	8 p.m. to 10 p.m.
Average transpiration	13.43	52.27	88.08	99.21	87.23	67.57	35.08	6.00
		**	**	**	**	**	**	**
Average air temperature (F)	60.4	65.6	72.3	74.4	75.3	74.5	70.8	65.8
Average relative humidity (%)	71	69	61	59	56	56	60	65

** 1% level significance

the same period as in the cabbage trial in the greenhouse (C-1), i.e. from 12 noon to 2 p.m. The results showed that significant increases were found between each two-hour period before 12 noon and that significant decreases were also found between each two-hour period after 2 p.m. Increases in the air temperature and decreases in the relative humidity occurred up to 2 p.m. and 4 p.m., but decreases in the air temperature and increases in the relative humidity were found to occur after that period of the day. The significant increases in transpiration were found to coincide with the environmental changes only before 12 noon and after 6 p.m. Although the highest temperature and the lowest relative atmospheric humidity during the day in the greenhouse were found in the two-hour periods of 2 to 4 p.m. and 4 to 6 p.m., the maximum transpiration period did not occur in these periods of the day. Whether the light intensity would cause the highest transpiration in the period of 12 noon to 2 p.m. or the higher temperature would reduce transpiration in the period of 2 to 4 p.m. was not properly examined in this trial.

The average results and the significant differences in the transpiration in a 24-hour period under both greenhouse and growth chamber conditions are presented in Table 20. The results of transpiration in the greenhouse were similar to those in the growth chamber, but a higher and more erratic pattern was found in the greenhouse. It is obvious that the greenhouse results were caused by environmental

Table (20). Transpiration in Grams of Water per Potato Plant During a 24-Hour Period in the Greenhouse and the Growth Chamber, as well as the Temperature Records of the Greenhouse on the Day of the Trial (Trial P-2)

Measurements	Days after planting											
	14	21	28	35	42	49	56	63	70	77	84	91
Transpiration (growth chamber)	9.6	62.6	127.5	179.5	325.0	329.2	342.9	326.6	325.4	326.1	310.8	269.6
		**	**	**	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Transpiration (greenhouse)	23.9	139.1	268.4	244.0	562.6	563.9	230.7	740.2	611.4	767.1	882.8	741.2
		*	*	N.S.	**	N.S.	**	**	*	**	*	**
Maximum day temperature (°F)	95	96	89	83	80	74	68	76	78	80	84	74
Minimum day temperature (°F)	61	62	58	62	57	57	57	52	54	58	64	62
Average day temperature (°F)	71.6	74.0	71.2	67.3	69.0	66.3	59.1	63.0	67.1	70.1	69.3	66.6

N.S. non-significant difference   * 5% level significance   ** 1% level significance

changes while plants in the controlled conditions of the growth chamber were only affected by their growth stages. The cloudy and rainy days were found to reduce plant transpiration while the measurements were conducted at the plant age of 35 to 56 days in the greenhouse. In the later season, a warm and sunny day was found to increase plant transpiration at 84 days, however, decreasing transpiration was found in the growth chamber at the same age. The results showed that the environmental factors could affect plant transpiration in both the early and later growing period although the amount of water loss was generally found higher after the middle growing period.

Plant transpiration in a 24-hour period in the growth chamber (Table 20) was found to rapidly increase from 14 to 42 days, but non-significant differences were found between 42 to 84 days. A significant decrease was found from 84 to 91 days after planting. The maximum transpiration per plant, according to the results, was found to occur at 56 days. It is obvious that the maximum transpiration occurred while the total growth of the leaves was within 7 days of its maximum and the tuber growth was starting to rapidly increase.

Plant growth-transpiration regression studies

The results of these studies showed a good correlation between transpiration and total plant growth, as well as transpiration and leaf growth (Table 21). A

Table (21). Summary of Plant Growth-Transpiration Regression Significance and Correlation Coefficient for Potato Plants (Trial P-2)

Measurements	Locations	
	Growth chamber	Greenhouse
Total fresh weight of the plant	** (0.78)	** (0.90)
Total dry weight of the plant	** (0.63)	** (0.87)
Fresh weight of the leaves	** (0.96)	** (0.76)
Dry weight of the leaves	** (0.95)	** (0.82)
Fresh weight of the tuber	** (-0.77)	N.S. (0.74)
Dry weight of the tuber	** (-0.82)	N.S. (0.72)

N.S. non-significant difference ** 1% level significance negative correlation and also a significant regression was found between the tuber growth and transpiration in the growth chamber, however, a non-significant regression was found when the transpiration measurements were carried out in the greenhouse. According to the results (Table 17 and 20 and Figures 15 and 16), the pattern of transpiration in the growth chamber had started to level off before the weight of the tuber started to increase significantly. On the other hand, it is also obvious that the rapid increase in the weight of the tubers did not cause any change in the transpiration per plant.

Transpiration rates per gram of plant weight

The results of transpiration rate in grams of water per gram of plant weight in a 24-hour period are presented in Table 22 and Figure 19. These results showed that the maximum rates were found at 21 days after planting in all measurements. Generally, the decreasing transpiration rate was found to be more rapid in these measurements based on per gram of both fresh and dry weights of the total plant than that based on per gram of both fresh and dry weights of the leaves. This was due to the tuber growth which did not contribute to an increase in transpiration, but seemed to decrease it. Although the transpiration rates based on the total plant weight showed a rapid decrease from 42 to 49 days, non-significant differences were found after

Table (22). Transpiration Rates in Grams of Water per Gram of Potato Plant Tissue During a 24-Hour Period in the Growth Chamber (Trial P-2)

Measurement	Days from planting											
	14	21	28	35	42	49	56	63	70	77	84	91
Total fresh wt. of the plant	0.70	1.33	0.89	0.72	0.80	0.60	0.54	0.42	0.35	0.33	0.27	0.27
		**	**	*	N.S.	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Total dry wt. of the plant	10.53	17.64	13.50	11.21	11.11	6.93	6.32	4.18	3.02	2.72	2.02	1.76
		**	**	N.S.	N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Fresh weight of the leaves	1.18	2.25	1.39	1.20	1.44	1.20	1.15	1.04	1.09	1.13	1.08	1.43
		**	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Dry weight of the leaves	17.71	24.49	18.82	16.70	17.99	13.36	13.99	12.20	12.42	13.64	12.18	12.15
		**	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S. non-significant difference * 5% level significance ** 1% level significance

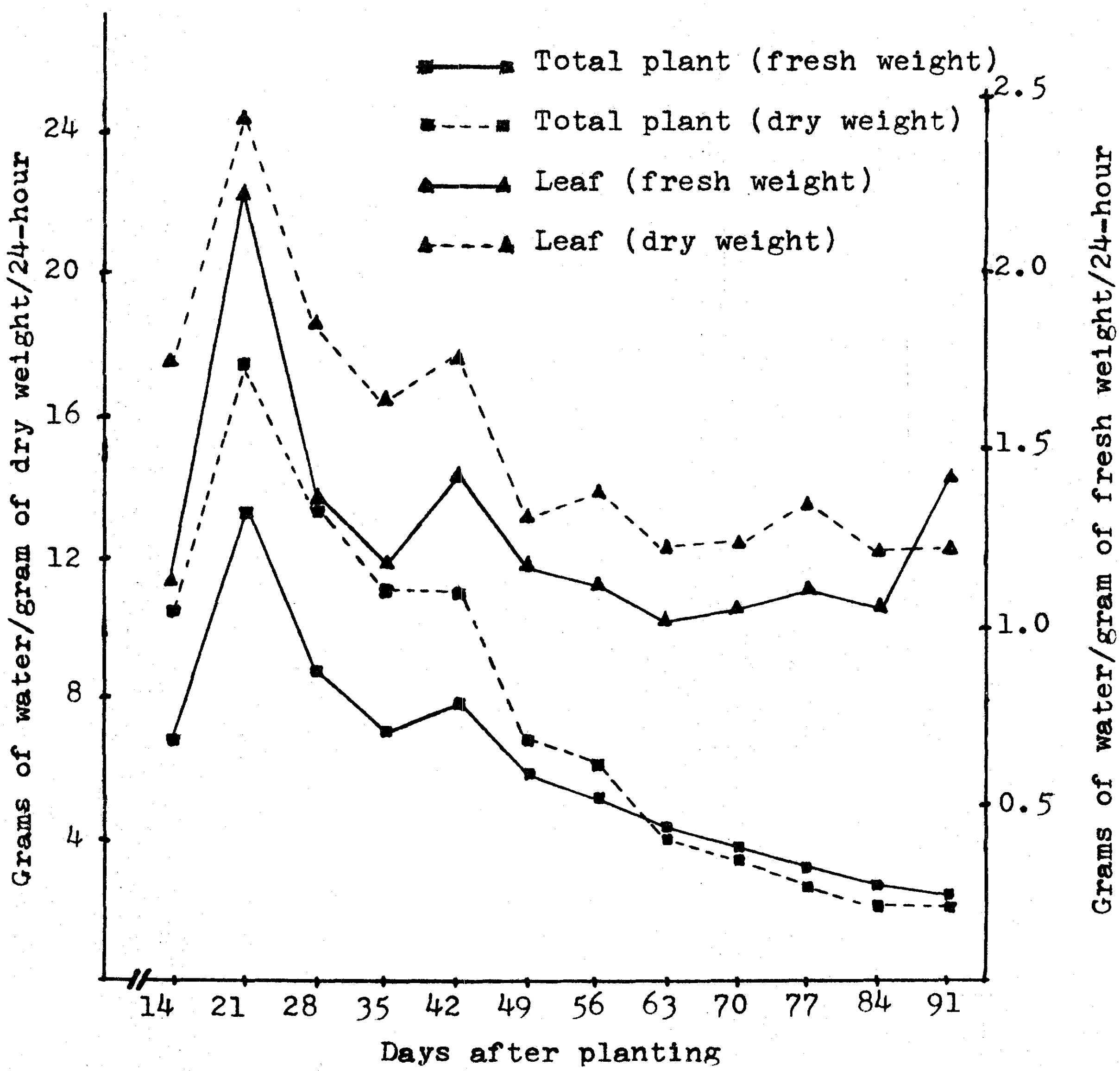

Figure 19 : Transpiration rates in grams of water per gram of plant weight in a 24-hour period in the growth chamber. (Potato Trial P-2, summer 1969)

49 days, while transpiration rates based on the leaf weight showed non-significant differences after 28 days.

Estimated total water usage

The results of the plant transpiration per plant at the various stages of growth have been discussed in a previous section, but again the increases in the water content of the plant have not been considered. According to the results in Table 23, the increases in the retained water were found to increase up to the period between 35 and 42 days (71 gallons per day per acre). The estimated total water usage was found to increase up to the period between 56 and 63 days (1231 gallons per day per acre). In the greenhouse trials (Table 20), transpiration showed an erratic pattern depending upon climatic conditions. Calculated values of gallons of water per day per acre are not presented for this trial, but the highest water usage was estimated at 3087 gallons per day per acre of transpiration only. Again, it should be remembered that these were single-stemmed plants and the use of water would have been much greater with multiple-stemmed plants ordinarily used in cultivation.

Potato Trial P-3

Plant growth and development

Table (23). Estimated Water Usage by Potato Plants in Gallons of Water per Day per Acre (Trial P-2)

Plant ages in days	Average plant transpiration in the growth chamber	Water retained within plant tissues	Estimated total water usage
14 to 21	127 (1188)	15 (140)	142 (1328)
21 to 28	333 (3115)	45 (421)	378 (3536)
28 to 35	537 (5023)	51 (477)	588 (5500)
35 to 42	882 (8250)	71 (664)	953 (8914)
42 to 49	1144 (10701)	61 (571)	1205 (11272)
49 to 56	1175 (10991)	41 (381)	1216 (11372)
56 to 63	1170 (10944)	61 (571)	1231 (11515)
63 to 70	1140 (10663)	53 (496)	1193 (11159)
70 to 77	1139 (10654)	33 (309)	1172 (10963)
77 to 84	1114 (10420)	54 (505)	1168 (10925)
84 to 91	1015 (9494)	-58 (-543)	957 (8951)

Note : 13200 plants per acre (14" spacing x 34" row width)
( ) indicate liters of water/day/hectare

The plant materials for this trial were grown in the field during the summer of 1969. A summary of the average growth and plant transpiration, as well as a summary of significances from analysis of variance studies, are presented in Table 24, while a summary of growth rates of the plant is presented in Table 25. According to the results in Table 24, the pattern of plant growth (Figures 20 and 21) in the field was more erratic than the two potato trials in the greenhouse (P-1 and 2). These differences were probably due to the fewer experimental replications, environmental factors, or both.

Generally, the fresh and dry weights of the total plant (Table 24) were found to increase up to 75 days and 89 days after planting, respectively. It is obvious that the dry weight continued to increase to very near the end of the growing season. The maximum total fresh weight was found at 75 days, while the maximum total dry weight was found at the last harvest. The maximum growth rate (Table 25) in grams per week of the fresh weight of the total plant was also found seven days earlier than that of the dry weight of the total plant, i.e. 61 days and 68 days, respectively. It is obvious in the results that the decline in growth rate of the fresh tissue and negative values in the later period of the season is due to drying out and loss of the older leaves.

The fresh and dry weights of the leaves were generally found to increase up to 75 days (Table 24), but

Table (24). Average Weights, Measurements and Transpiration per Plant in a 24-Hour Period, as well as a Summary of Significances from Analysis of Variance Studies on Potato Plants (Trial P-3)

	Days from planting														
Measurements	40		47		54		61		68		75		82		89
Total fresh weight of the plant (gm)	34.6	*	114.5	N.S.	171.1	**	341.5	N.S.	395.7	**	612.7	*	540.2	N.S.	589.9
Total dry weight of the plant (gm)	2.3	N.S.	9.2	*	18.2	**	39.7	*	48.3	**	80.5	N.S.	82.6	**	94.7
Fresh weight of the leaves (gm)	24.3	**	79.7	N.S.	98.1	*	151.6	N.S.	145.6	N.S.	171.4	**	102.5	N.S.	69.3
Dry weight of the leaves (gm)	1.8	*	7.1	N.S.	10.2	*	16.1	N.S.	14.9	*	19.9	*	14.4	N.S.	13.3
Fresh weight of tubers per plant (gm)	-		-		23.0	**	108.5	*	170.2	**	325.0	N.S.	349.5	**	437.0
Dry weight of tubers per plant (gm)	-		-		3.1	*	15.8	N.S.	25.8	**	50.0	*	60.6	**	75.5
Fresh weight of each tuber (gm)	-		-		2.63	N.S.	4.99	N.S.	7.81	**	17.93	N.S.	16.37	*	20.05
Dry weight of each tuber (gm)	-		-		0.38	N.S.	0.72	N.S.	1.18	**	2.73	N.S.	2.83	*	3.46
Equatorial diameter of the tuber (cm)	-		-		1.37	**	1.75	**	2.09	**	2.60	N.S.	2.59	N.S.	2.69
Polar diameter of the tuber (cm)	-		-		1.81	N.S.	2.11	*	2.46	**	3.25	N.S.	3.06	N.S.	3.25
Height of the stem (cm)	7.4	**	14.2	*	19.4	**	28.1	N.S.	26.4	N.S.	32.7	N.S.	30.9	N.S.	30.5
Transpiration gm water/plant/24 hr.	54.4	**	528.6	*	314.0	**	704.8	N.S.	627.2	N.S.	763.8	N.S.	638.2	**	363.6

Table (25). The Growth Rates per Week of the Total Plant and Selected Plant Parts at the Different Ages of Potato Plant (Trial P-3)

Measurements	Days after planting 40	47	54	61	68	75	82	89
Total fresh weight of the plant (gm)	15	65	120	155	117	53	-8	-47
Total dry weight of the plant(gm)	2	6	15	17	22	19	9	2
Fresh weight of the leaves (gm)	15	41	37	31	10	- 8	-59	- 76
Dry weight of the leaves (gm)	1.0	4.3	3.8	3.0	2.0	- 0.3	- 2.8	- 7.3
Fresh weight of tubers per plant (gm)	-	-	18	70	103	100	63	17
Dry weight of tubers per plant (gm)	-	-	5	12	18	16	13	7
Height of the stem (cm)	3	6	5	5	3	2	0	0

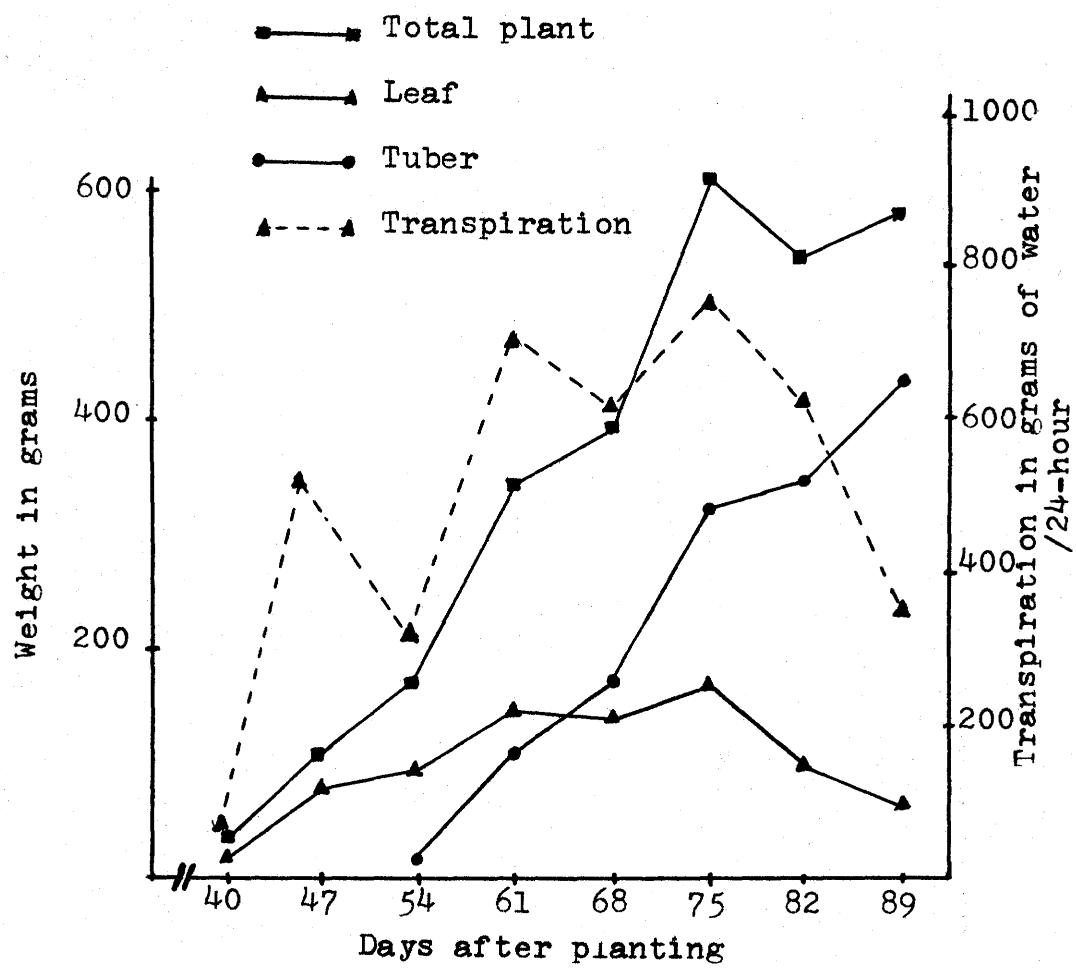

Figure 20 : Fresh weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the field, at different ages. (Potato Trial P-3, summer 1969)

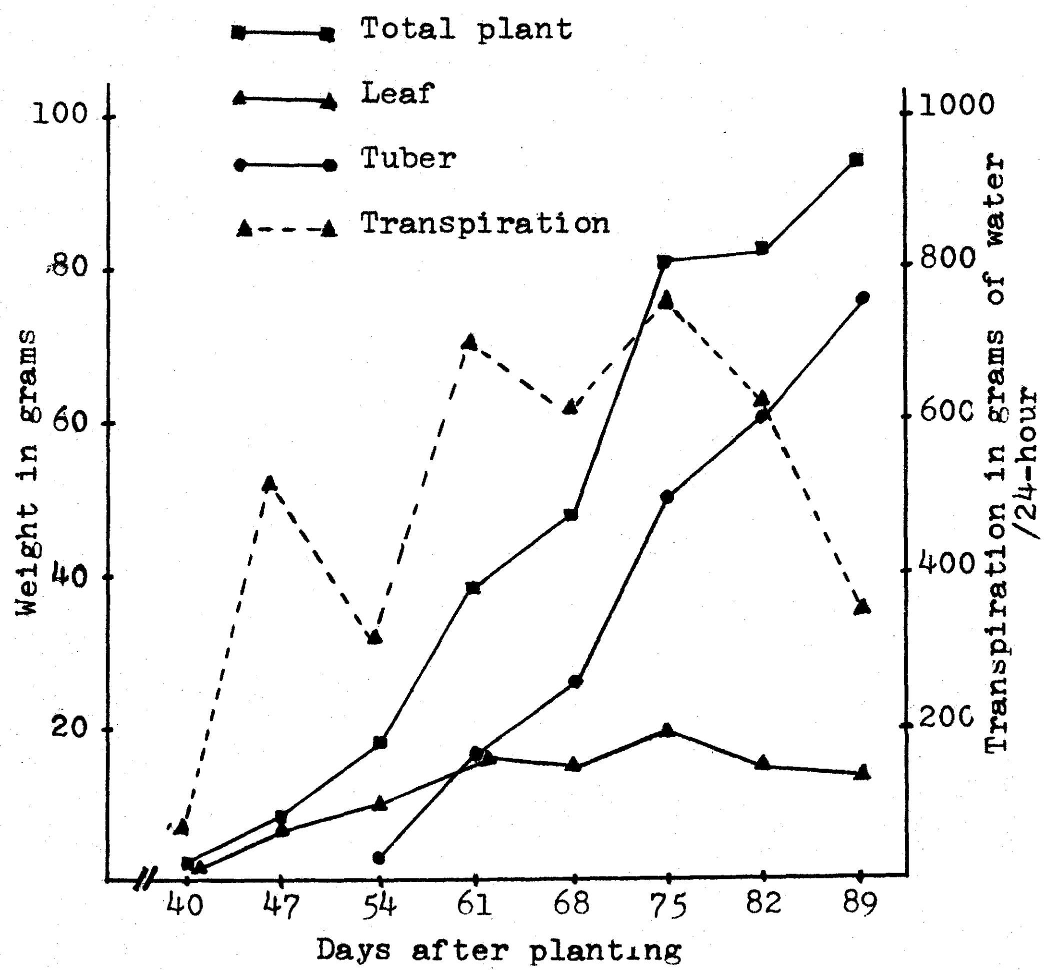

Figure 21 : Dry weights of the total plant and plant parts, as well as the transpiration per plant in a 24-hour period in the field, at different ages. (Potato Trial P-3, summer 1969)

there was a significant decrease from 75 to 82 days and a non-significant decrease was found from 82 to 89 days after planting. Although there was a general increase in growth up to 75 days, only some of the weekly periods showed significant increases. The maximum weekly rates of increase in both fresh and dry weights (Table 25) were found at the same age (47 days), while the maximum total leaf growth (Table 24) was found at 75 days after planting. Senescence was probably the major reason causing the decreased leaf weights or negative growth rate after 75 days.

The height of the stem was found to increase significantly from 40 to 61 days, and non-significant differences were found after 61 days (Table 24). The higher growth rates (Table 25) of the stem in centimeters per week were found from 47 to 61 days which was also the period for the higher growth rates of the leaves.

The tuber growth (Table 24) was found to increase significantly in both fresh and dry weights during the whole tuber growing period, except from 75 to 82 days for the fresh and from 61 to 68 days for the dry weight, respectively.

According to the results (Table 25 and Figures 22 and 23), the maximum weekly rates of increase in both fresh and dry weights of the tuber occurred at 68 days, but another high rate of increase was also found at 75 days. Obviously, the growing period for maximum tuber growth was from 68 to 75 days after planting. Both the fresh anddry

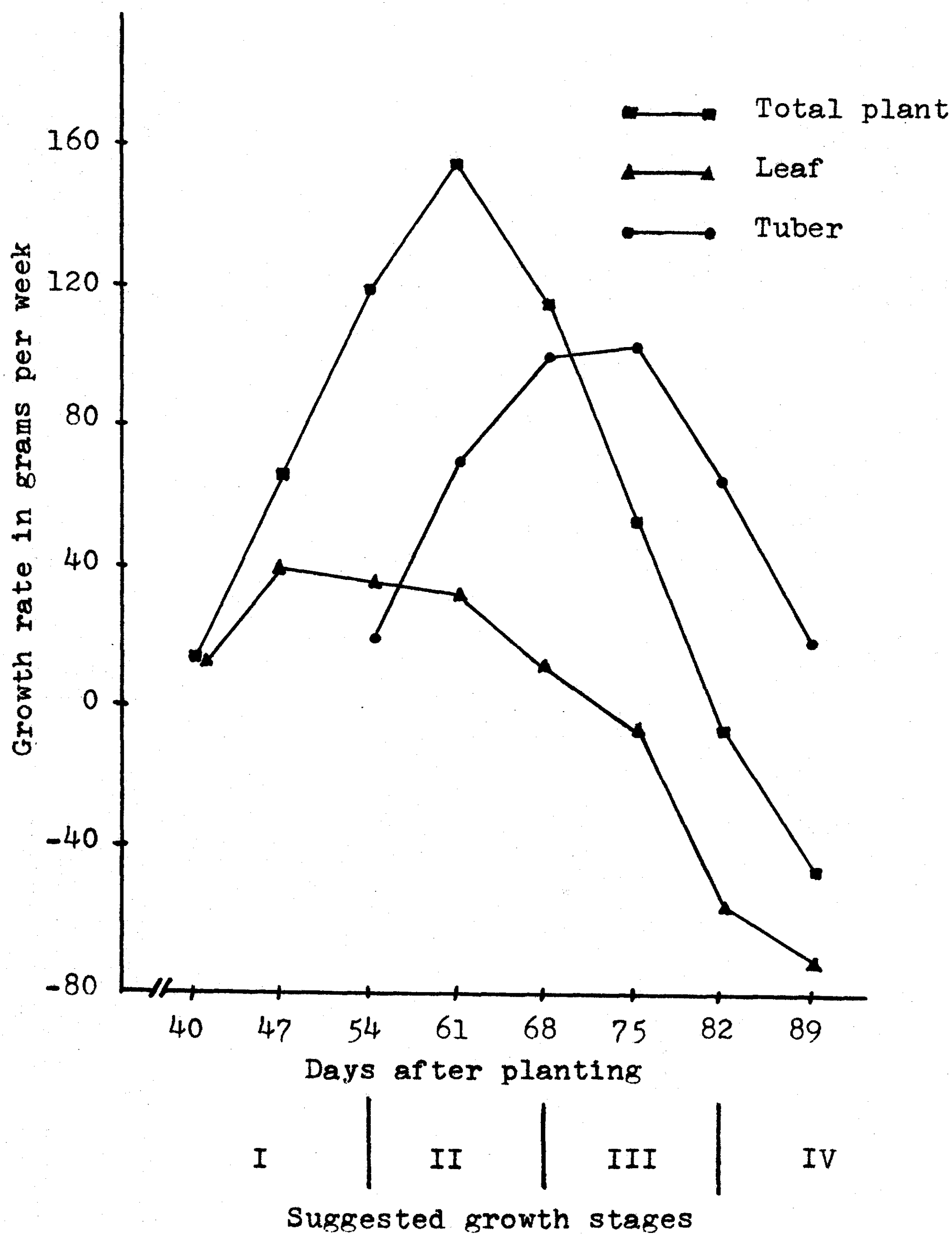

Figure 22 : Growth rates in grams of fresh weight per week of the total plant and plant parts in the field, as well as the suggested growth stages. (Potato Trial P-3, summer 1969)

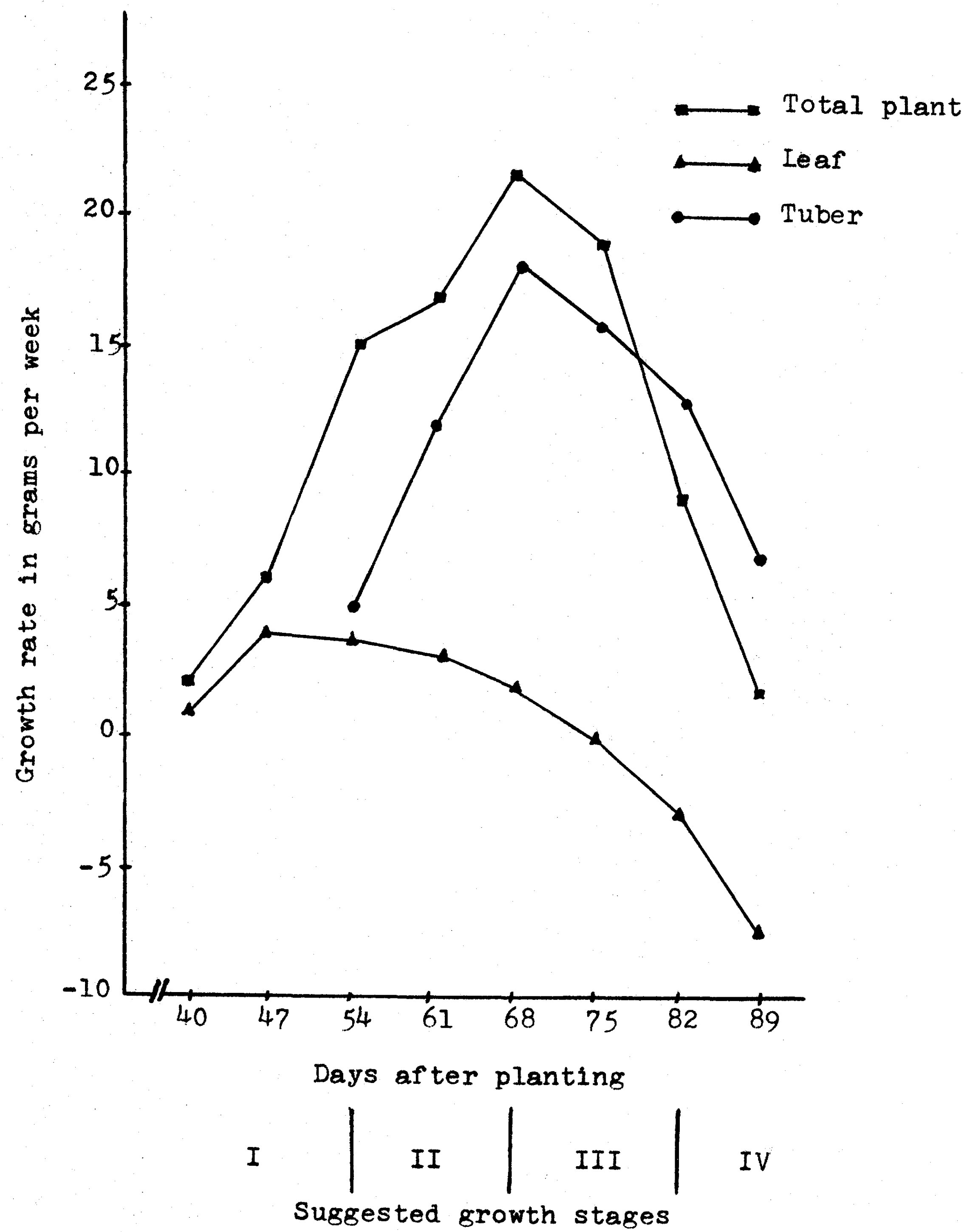

Figure 23 : Growth rates in grams of dry weight per week of the total plant and plant parts in the field, as well as the suggested growth stages. (Potato Trial P-3, summer 1969)

weights of each tuber were found to increase significantly from 68 days up to the last harvest except for the period from 75 to 82 days. The equatorial diameter of the tuber was found to increase significantly during the period from 54 to 75 days,while the polar diameter of the tuber increased significantly during the period from 61 to 75 days. However, both of them (equatorial and polar diameters) were found to increase significantly earlier than the period of the significant increases in the weight of each tuber. According to these results, it is obvious that the rapid increases in the tuber volume (both equatorial and polar diameters) occurred in the early tuber growing period.

Although the results of plant growth (Table 24) were more variable than the two potato trials in the greenhouse, the growth patterns (Figures 20 and 21) were similar.

The total growing period was also arbitrarily divided into four stages. They were

I. The young plant stage (up to 54 days);

II. The transition growth stage (from 54 to 61 days);

III. The maximum tuber growth stage (from 61 to 82 days); and

IV. The tuber ripening and plant senescence stage (after 82 days).

The plant materials in this trial were found to grow slowly and their size was also smaller compared to those plants in the greenhouse (P-1 and 2). This was probably due to frost damage in the early season and relatively high transpiration per plant which might have caused wilting in some period in the growing season. Thus, Stage I was continuing up to 54 days after planting.

Plant transpiration

The results of plant transpiration in the field also showed a much more erratic pattern than was shown in the growth chamber. The high transpiration per plant at 47 days (Figures 20 and 21, Table 24) was probably due to high maximum temperature, but the lower maximum temperature and lower wind speed would be the two major factors affecting the reduced transpiration at 54 days (Table 26). These results also showed that the transpiration per plant tended to coincide with the period of greatest plant growth. Although the total plant growth was smaller than the last two trials (P-1 and 2), the transpiration per plant was found higher.

Plant growth-transpiration regression studies

The results of the regression significance test and the correlation coefficients between plant growth and transpiration per plant were as follows:

- total fresh weight of the plant - N.S. (0.62),
- total dry weight of the plant - N.S. (0.50),
- fresh weight of the leaves - * * (0.89),

Table (26). A Summary of Weather Records* During Transpiration Measurements Conducted in the Field (Trial P-3)

Plant age	Air temperature (°F)			Lowest R.H.%	Max. wind speed m.p.h.	Duration of bright sunshine hrs/day
	Max.	Min.	Mean			
40	62	51	56.5	46	19	3.4
47	85	50	67.1	43	22	11.6
54	74	47	60.1	43	16	14.3
61	80	57	68.1	26	20	14.9
68	84	55	69.1	42	20	13.8
75	81	55	66.0	30	20	8.5
82	63	39	51.0	28	27	3.8
89	84	55	69.5	34	27	10.7

* records from Saskatoon Airport Weather Office

dry weight of the leaves - * * (0.86),
fresh weight of the tuber - N.S.(0.12), and
dry weight of the tuber - N.S.(0.05).

These results were similar to that in the potato trial in the greenhouse(P-1). Again, according to the results, the transpiration per plant under field conditions was found to be significantly related to both the fresh and dry weights of the leaves. On the other hand, the relationship between transpiration and tuber growth was non-significant.

Estimated total water usage

Because the transpiration and plant growth showed a very erratic pattern, the estimated total water usage was only considered for transpiration. The maximum total transpiration was 2671 gallons per day per acre. Unfortunately, this trial under field conditions was not conducted by use of the lysimeter or the tent method, therefore, the evaporation from the soil surface, as well as the transpiration from multiple-stemmed plants per hill should be taken into account for the total amount of irrigation water needed.

Potato Trial P-4

Plant growth and transpiration

The plant materials for this trial were grown in the growth chamber with constant environmental conditions ($60^{\circ}F$ night, $70^{\circ}F$ day, and 2500 fc light).

The results (Table 27) showed that there was a significant increase in both fresh and dry weights of the total plant from 10 to 17 days after planting, but the increase in the fresh weight was more rapid than in the dry weight. The fact that the plants were smaller at 17 days in this trial compared to those plants at 14 days in the potato trial in the greenhouse (P-1) was probably due to the lower temperature and the lower light intensity.

The transpiration per plant was found to rapidly increase from 10 to 17 days. However, the transpiration per plant at 17 days in this trial was also smaller than at 14 days in the potato trial in the greenhouse (P-1). Obviously, because the plants were smaller, the transpiration was also less.

This small trial was conducted because these early stages had not been recorded in the previous experiments. Obviously, these significant increases in both plant weights and transpiration would likely have been masked if the entire experiment from emergence to maturity had been carried out (see Trial P-1,2,3).

Table (27). Average Weights and Plant Transpiration, as well as a Summary of Significances from Analysis of Variance Studies on Potato Plants (Trial P-4)

Measurements	Days after planting 10		17
Total fresh weight of the plant (gm)	3.00	** →	7.68
Total dry weight of the plant (gm)	0.24	* →	0.54
Transpiration per plant (gm of water/24-hour)	5.96	** →	7.12

* 5% level significance, ** 1% level significance

SUMMARY AND CONCLUSIONS

During a two-year period (1968-70), plant growth and transpiration, as well as estimated water usage, involving the cabbage cultivar Golden Acre and potato cultivar Norland, were examined and measured during the growing period. The plant growth was taken by both fresh and dry weights of the total plant and plant parts. From these weekly measurements the growth rates were calculated. The weighing method was used for all of the transpiration measurements which included both a 2-hour and a 24-hour period. The transpiration measurements were carried out in the growth chamber and greenhouse on plants grown in the greenhouse and under field conditions for the plants grown in the field.

The plant growth studies with cabbages showed that the head started to increase significantly in size when the unfolded leaves reached their maximum weight. Both the unfolded leaf growth and head growth contributed to the total plant weight, but the former only influenced the total before head formation, while the head growth strongly affected the total plant weight in the later growing period. The head growth, however, showed that appreciable increases in head volume occurred before increases in weight. Four growth stages seemed evident in the growing period, namely, unfolded leaf growth (Stage I), transition from leaf to head (Stage II), head enlargement (Stage III) and maturity or plant senescence (Stage IV). The growth rate study showed that the maximum growth rate of the unfolded leaves occurred during Stage I, while the maximum growth rate of both head and total plant was shown in Stage III. The maximum weekly rate of increase in the fresh weights of different plant parts, as well as total plant, occasionally appeared to be earlier than that of the dry weights. The cabbage plants grown under field conditions (C-2) were smaller than those in the greenhouse (C-1). This was probably due to the climatic effects on plant growth that might led to early maturity.

The weight of the unfolded leaves showed a good correlation to transpiration in a 24-hour period in the growth chamber. Generally, the rapid increases in head growth coincided with the levelling off in transpiration per plant during Stage II, continued through Stage III and then rapidly decreased in Stage IV. Because of climatic effects, the transpiration in both the greenhouse and the field for a 24-hour period was erratic, but the pattern was similar with the higher transpiration occurring in Stages II and III. Furthermore, plants subjected to the natural variations during the day showed that the highest amount of transpiration occurred in a 2-hour period from 12 noon to 2 p.m.

There was not only the levelling off in transpiration per plant, but also continued increase in the weight of the total plant in both Stages II and III. Thus, transpiration rates in grams of water per gram of total cabbage plant in a 24-hour period in the growth chamber were found to decrease rapidly in these growth stages.

Although the estimated total water usage by the cabbage plants was rather small at the beginning of the experiment in the growth chamber (247 gallons per day per acre), the results showed that a maximum rate of 1113 gallons was being used at Stage III. With the greenhouse and field trials a maximum rate of 2148 gallons and 2315 gallons, respectively, was also estimated.

The growth studies on the potatoes showed that the leaves and stems mainly reached their maximum weight before the tuber started to grow rapidly. According to the growth pattern of the potato plants, tuber growth strongly contributed to the total plant weight after the on-set of tuber formation. In fact, the above-ground parts stopped growing when the tuber started to increase significantly in weight. The single tuber growth showed that significant increases in volume (both equatorial and polar) occurred before significant increase in weight. Four growth stages were also evident with potatoes, namely, shoot growth (Stage I), transition from shoot to tuber (Stage II), tuber growth (Stage III) and tuber maturity or plant senescence (Stage IV). Generally, flowering was the indicator of Stage II and tuber initiation occurred at this time in the trials conducted during the normal growing period, but in the winter trial tubers were initiated earlier.

The weight of the leaves showed a good correlation to transpiration in a 24-hour period in the growth chamber. Generally , the transpiration started to level off after the on-set of tuber formation, and the transpiration per plant maintained a constant amount of water loss during the tuber growing period then decreased in Stage IV. Although transpiration per plant seemed to remain relatively unchanged during Stages II and III, the plant continued to increase in weight and the transpiration rates in grams of water per gram of total potato plant rapidly decreased. The highest transpiration in a 2-hour period of the day under the greenhouse conditions also occurred at 12 noon to 2 p.m. with potatoes.

With the potato plants the estimated water usage in the growth chamber was small amount at the beginning of the experiment (276 gallons for P-1 and 142 gallons for P-2). The maximum rate of 1609 gallons (P-1) per day per acre was also found at Stage III. Due to climatic effects on transpiration, the maximum water usage in the greenhouse and field was higher than that in the growth chamber, i.e. 3087 gallons and 2671 gallons per day per acre, respectively.

The following conclusions were made :

1. The growth pattern of the cabbage and potato plants consisted of four stages; namely, the unfolded leaf growth, transition from leaf to head, head enlargement, and head maturity or plant senescence with the cabbage plants and the shoot growth, transition from shoot to tuber, tuber growth, and tuber maturity or plant senescence with the potato plants.
2. Both unfolded leaf growth of the cabbage plants and leaf growth of the potato plants were found to be significantly correlated to transpiration during the whole growing period.
3. The transpiration per plant in a 24-hour period increased until the head (cabbage) and tubers (potato) started to develop.
4. The high transpiration per plant after head (cabbage) and tuber (potato) formation was generally maintained for a period of time and then decreased as the stage of plant senescence occurred.
5. The highest transpiration in a 2-hour period was from 12 noon to 2 p.m. for both cabbage and potato plants.
6. The maximum estimated water usage (excluding evaporation from soil surface) under controlled

growth chamber conditions was 1113 gallons for cabbage and 1609 gallons for potatoes and of this amount the water retained in the plant tissues accounted for 10 per cent with cabbage and 2 per cent with potatoes. Under greenhouse conditions the transpiration alone was 2148 gallons and 3087 gallons for cabbage and potatoes, respectively, and in the field with even smaller plants the transpiration was 2313 gallons for cabbage and 2671 gallons per day per acre for potatoes.

It is also suggested that the lysimeter method for the field studies should be used in future studies to determine the total evapotranspiration from the cropped surface during the growing season in order to obtain more practical results for irrigation programs for vegetable growers.

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