Int. J. Sustain. Crop Prod. 2(5): 01-07 (November 2007)

PARTITIONING OF DRY MATTER AND GRAIN YIELD POTENTIAL IN MAIZE (*Zea mays* L.) AS INFLUENCED BY PLANT DENSITY, RATE AND TIMING OF NITROGEN APPLICATION

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Accepted for publication: July 07, 2007

ABSTRACT

Amanulluh. 2007. *Partitioning of Dry Matter and Grain Yield Potential in Maize (Zea mays L.) as Influenced by Plant Density, Rate and Timing of Nitrogen application*. **Int. J. Sustain. Crop Prod. 2(5): 01-07**

Efficient use of nitrogen is considered as one of the most important input needed for increasing productivity in maize. In order to study the response of dry matter partitioning and grain yield potential in maize to plant density, rate and timing of nitrogen application an experiment was designed and conducted at the Agriculture Research Farm of the NWFP Agricultural University, Peshawar for two consecutive years in summer 2002 and summer 2003. Factorial experimental treatments were two plant densities (60,000 and 100,000 plants ha^{-1}) and three nitrogen rates (60, 120 and 180 kg N ha^{-1}) applied to main plots, while six split application for N in different proportions were applied to subplots at different growth timings of maize (cv. Azam), in two equal, three equal, three unequal, four equal, five equal and five unequal splits at sowing and with 1st, 2nd, 3rd & 4th irrigation at two weeks intervals. The crop was irrigated at two weeks interval i.e. 14, 28, 42, and 56 days after emergence. Data was recorded on dry matter content (g) of leaf, stem, ear, ear sheath, tassel, plant and grain yield. Increasing N rates significantly enhanced the dry matter content of all the parameter studied except tassel weight. Similarly except tassel and ear sheath weight the dry matter content of all other parameters was significantly increased with increase in number of split application for N. Plant density had no significant effect on the dry matter content of all the parameters under study. Years had only significant affect on ear dry matter and grain yield plant^{-1}. Higher rate of 180 kg N ha^{-1}, about 50 % more than recommended rate for maize with four or five splits increased dry matter content and grain yield plant^{-1} is therefore recommended for the irrigated tracts and high rain fall areas of Pakistan in general and in NWFP in particular which contribute more than 50% of the total country production in maize.

Key words: Dry matter partitioning, grain yield, plant density, nitrogen

INTRODUCTION

Nitrogen fertilizer is universally accepted as a key component to high yield, high seed quality and optimum economic return. Increase in N levels increases plant growth rate, leaf area index, and grain yield. Agronomic approaches, such as fertilizer placement, proper level of fertilizer application in optimum plant density and time of fertilizer application, keep plant-available nitrogen in the plant root zone (Hauck, 1984). Grain yield showed positive relationship with kernel number per plant and harvest index. Reduction in N rate reduces grain yield by 43-74% and number of kernel per plant by 33-65% (Andrea et al., 2006). Grain yield and partitioning of dry matter in maize increases by increasing plant uptake and use of nitrogen at proper growth stage. Restriction of N supply from seeding to V8 caused an irreparable reduction in ear size and kernel yield up to 30%, while withholding N supply from V8 to maturity reduced kernel yield by 22% and N uptake by 53% (Subedi and Ma, 2005). Delaying N application till the V6 stage resulted in a near 12% reduction in maximum kernel yield (Binder et al., 2000). Nitrogen deficiency in maize decreases cell division and cell elongation, which in turn resulted in decreased leaf length and prolonged time for leaf development. Nitrogen deficiency significantly increases both bulk and segmental cell wall per-oxidase activity in the growth zone, thus showing an interaction between leaf growth cessation and enzyme activity (Jovanovic et al., 2004). High levels of N application during the reproductive stage not only increase proteins in the grains but also partition greater amounts of carbohydrates to the grains. Maize hybrids which accumulate more N after silking tending to have higher grain yield (Akintoye *et al*., 1999). Nitrogen uptake and nitrogen nutrition index at silking is positively correlated to grain yield (Bertin and Gallais, 2000). Nitrogen uptake during the vegetative stage is used primarily for vegetative growth, and during late vegetative periods for reproductive organs initiation, whereas the N applied after silking and tassling is mainly directed towards the synthesis of grain proteins (Akbar *et al*., 1999). Increased productivity in maize genotypes is due to their ability to accumulate nitrate in their leaves during vegetative growth and to efficiently remobilize this stared nitrogen during grain filling (Hirel *et al*., 2001). Addition of N at the flowering stage not only increased grain yield but substantially improve grain quality (Mengal and Kirkby, 1979). Greater dry matter accumulation in maize is associated with greater leaf longevity. Number of green leaves, an indicator of leaf longevity, was greatest when supply and demand of assimilates during grain filling were approximately equal. Leaf longevity was enhanced by an increase in soil N. Increased leaf longevity in maize hybrids is associated with a larger source: sink ratio during grain filling (Rajcan and Tollenaar, 1999). Highest biomass yield was obtained at 120 kg N ha^{-1} in first year one and at 160 kg N ha^{-1} in 2nd year. Maize crop differs in its ability to maintain LAI, CGR and above ground dry matter production at different levels of N supply. Optimizing the inputs of N at the farm level would maximize biomass production and harvest index Pandey et al. (2000). The effects of plant population and nitrogen were statistically significant in ear height, ear diameter, seed number per ear, fresh ear weight, number of ears per plant and fresh ear yield. Plant population x nitrogen level interaction in fresh ear yield was also significant Turgut (2000). Grain number per ear and test weight increased with decreasing plant density Sing et al. (1997). Increasing N fertilizer increase ear and grain yield in different plant populations. When N was limiting ear and grain yield increased with population up to around 90 000 plants ha^{-1}, and then remained unchanged with further increase in plant population. Quality characteristics such as ear size and individual grain weight were consistently improved by the application of N throughout the range 30 000-140 000 plants ha^{-1}, compared when N was not applied. Ear size and individual grain weight declined with increase in population; regardless of N supply Stone et al. (1998). Grain yield per plant was directly affected by ear length, grains per row, ears per 100 plants and seed Soliman et al. (1999). Increasing plant density increases grain yield because of improvement in light interception during the critical period for grain set Andrade et al. (2002). Seed weight increased with increase in N rate (Raja, 2003). Seed weight increase with increase in N rate in both thin as well as in thick population, while weight declined in thick population when N level was not increased (Stone *et al.,* 1998). Seed weight increase with increase in N rate and number of splits (Purcino, 2000; Rajcan and Tollenaar, 1999), decreased with increase in plant density (Singh *et al.,* 1997). Grain yield increased with increase in plant density (Toller *et al*., 1999; Yogananda *et al*., 1999; Modarres *et al*., 1998; Gaurker and Bharad, 1998; Anjum *et al*., 1992 and Mariga *et al*., 2000), and decreased with decrease in plant density (Chiesa *et al*. 2000), increase in the rate of N (Purcino *et al*., 2000; Pandey *et al*., 1999; Gaurker and Bharad, 1998; Anjum *et al*., 1992, and Mariga *et al*., 2000), and increase with increase in the number of split application for N (Mariga *et al*., 2000; Gomachadze, 1999; and Scharf *et al*., 2002). In order to increase maize productivity the package of latest production technology involving the use of proper amount of N fertilizer at appropriate time and optimum plant population needs to be developed. Both inadequate and dense plant densities result in low maize yield even if the crop is fully fertilized. Experiment to determine the response of maize to different plant densities, and different nitrogen levels applied at different growth timings of maize is very important part of research in Pakistan. Therefore, the experiment was carried out with an objective to study the effect of plant density, N rates and timings for enhancing partitioning of DM to maximize grain yield.

MATERIALS AND METHODS

In order to study the response of grain yield and partitioning of DM in maize to plant density, rate and timing of nitrogen application an experiment was designed and planted at the Agriculture Research Farm of the NWFP (North West Frontier Province) Agricultural University, Peshawar during summer 2002 and summer 2003. The experimental farm is located at 34.01^{o} N latitude, 71.35^{o} E longitude at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1600 km north of the Indian Ocean and has continental type of climate. The research farm is irrigated by Warsak canal from river Kabul. Soil was clay loam, low in organic matter (0.87 %), P (6.57 ppm), K (121 ppm) and alkaline with high pH (8.2) and was calcareous in nature (Appendix I). The climatic data of the research farm is given in Appendix II. A sub-plot size of 4.2 m by 6 m, having 6 rows, 6 m long and 70 cm apart, was used. The 2 x 3 x 6 factorial experiment was conducted in RCB design with split-plot arrangement using four replicates. Factorial experimental treatments were two plant densities (60,000 and 100,000 plants ha^{-1}) and three nitrogen rates (60, 120 and 180 kg N ha^{-1}) applied to main plots, while six split application for N in different proportions were applied to subplots at different growth timings of maize (cv. Azam), in two equal splits (S1) i.e. 50% each at sowing and 14 DAE (days after emergence), three unequal splits (S2) i.e. 50% at sowing and 25% each at 14 and 28 DAE, three equal splits (S3) i.e. 33.3% each at sowing, 14 and 28 DAE, , four equal splits (S4) i.e. 25% each at sowing, 14, 28, and 42 DAE, five equal splits (S5) i.e. 20% each at sowing, 14, 28, 42 and 56 DAE, and five unequal splits (S6) i.e. 8.3, 16.6, 25, 33.3 and 16.6% at sowing, 14, 28, 42, and 56 DAE, respectively. Nitrogen as urea was applied with irrigation water at two weeks interval i.e.1st irrigation (14 DAE), 2nd irrigation (28 DAE), 3rd irrigation (42 DAE) and 4th irrigation (56 DAE). A uniform basal dose of 60 kg ha^{-1} P_2O_5 and 50 kg ha^{-1} K_2O was applied and mixed with the soil during seedbed preparation. The experiment was planted on 5th July in the year 2002 and 4th July in the year 2003. The plots were planted at high seed rate by drill and the two desired plant densities of 60,000 and 100,000 plants ha^{-1} were maintained in the different experimental units by thinning at the early vegetative growth timings of maize. Data were collected on seed yield, seed weight and protein concentration in seeds. At physiological maturity 10 plants were randomly harvested from the four central rows. Leaves, stem, ears, ear sheaths and tassels were separated, dried and weighed to record data on dry weight of leaf, stem, ear, ear sheaths and tassel. Dry weight plant^{-1} was calculated as sum of the dry weights of the plant components. Ears were threshed, grains ware counted, weighed and the grain yield per plant was worked out. Data was statistically analyzed and means were compared using LSD test (Steel and Torrie, 1980).

RESULTS AND DISCUSSIONS

Leaf weight plant^{-1}

Statistical analysis of the data (Table 1) indicates that N rates and N timing had significant effects on leaf weight plant^{-1}. Plant density had no significant affect on leaf weight plant^{-1}. Increase in the rate of N significantly increased leaf weight plant^{-1} from a minimum of 22.61 g at the lowest rate of N to a maximum of 26.70 g at the highest rate of N application. Plots which received N in five unequal splits produced the heaviest leaves (27.02 g plant^{-1}) followed, by 26.83 g plant^{-1}in the plots which received N in equal splits at five timings, while the slightest leaf weight of 20.92 g plant^{-1} was recorded in the plots to which N was applied in two equal splits. Increase in leaf weight plant^{-1} with increase in N rates and timings of N application is due to the increase in leaf size and chlorophyll content, delayed maturity time and increased vegetative growth period of maize which resulted in higher leaf weight plant^{-1}. These results are in confirmation with those of Rajcan and Tollenaar (1999) that increase in N rates increased leaf longevity and photosynthesis in maize which results in higher dry matter production. Similar results were reported by Pandey et al. (2000) and Turgut (2000) that dry matter production of maize increased with increase in the rate of N application.

Stem weight plant^{-1}

Nitrogen rate and timing of N application significantly affected stem weight plant^{-1} (Table 1). Years also had significant effect on stem weight. Maize grown in 2002 had higher stem weight plant^{-1} than maize grown in 2003. Increase in stem weight in 2002 might be due to the increase in rainfall during the middle stage of maize growth than in 2003. Increase in N rates increased stem weight from 40.81 g plant^{-1} when N was applied at the lowest rate (60 kg ha^{-1}) to 50.42 g plant^{-1} in the plots that received the highest rate of N (180 kg ha^{-1}). Heaviest stem weight of 50.17 g plant^{-1}was recorded in the plots to which N had been applied in five unequal splits (S_6), while the lightest stem weight of 40.52 g plant^{-1}was noted in plots to which N had been applied at two timings. Stem weight plant^{-1} increased with increase in N rates and timings of N application which may be due to the better nutrition of plants that increased leaf area and the processes of photosynthesis. The greater stem weight may have resulted from greater partitioning of assimilates to stem because when the N in root zone is more the shoot: ratio increase. These results are in confirmation with those of Pandey et al. (2000) and Turgut (2000) that increase in the levels of nitrogen results in higher dry matter production in maize.

Ear weight plant^{-1}

Combined statistical analysis of the two years data concerning ear weight indicates that year, N rates and timings of N application had significant effects on ear weight plant^{-1}, while plant density had no significant influence on ear weight (Table 1). Maize produced higher ear weight plant^{-1} at maturity in 2003 than in 2002. The variation in the ear weight in different years is due to the fluctuation in the rainfall. The higher ear weight in 2003 might be due to more rainfall at the late stage of maize that resulted in the maximum ear weight in 2003 than in 2002. Ear weight plant^{-1} showed positive relationship with N rates. Increase in N rates weight per ear also increased from a minimum of 108.26 g plant^{-1}at the lowest rate of N to a maximum of 122.88 g plant^{-1} at the highest rate of N. Plots which received N in five unequal splits (S6) gave the highest ear weight of 124.73 g plant^{-1}, followed by 120.69 g plant^{-1} in plots which received N in five equal splits (S5). The lowest ear weight of 101.42 g plant^{-1} was produced by those plots which received N in two equal splits. Ear weight plant^{-1} increased with increase in rates and timings of N application. It might be due to the better plant and ear development resulting from better nutrition which increased leaf chlorophyll content, net assimilation rate and assimilates during grain filling and development timings which resulted in the heavier ears. These results are in close conformity with those of Turgut (2000) who reported that increase dry matter production in maize is closely related with increase in the rates of nitrogen.

Tassel weight plant^{-1}

Data on tassel weight of maize at maturity are presented in Table 1. Combined statistical analysis of the two years data indicated that plant density, N rates and timings of N application had no significant effect on weight of tassel plant^{-1} at maturity.

Ear sheath weight plant^{-1}

Combined statistical analysis of the two years data presented in Table 1 showed that N rates influenced ear sheath weight of maize, while plant density and timings of N application had no significant effect on ear sheath weight plant^{-1}. Increasing N rates enhanced ear sheath weight from a minimum of 7.53 g plant^{-1} with the lowest rate of 60 kg N ha^{-1} to a maximum of 8.40 g plant^{-1} with the highest rate of 180 kg N ha^{-1}. Ear sheath weight plant^{-1} increased with increase in N rates and timings of N application which may be due to better plant growth and development resulting from better nutrition which increased leaf chlorophyll content, photosynthesis, net assimilation rate and more partitioning of assimilates to ear sheath which may have resulted in heavier ear sheath weight. These results are in confirmation with those of Rajcan and Tollenaar (1999) that increase in N rates enhanced leaf longevity and photosynthesis increases dry weight of ear sheath in maize.

Total weight plant^{-1}

Data pertaining to total weight plant^{-1} at maturity are presented in Table 1. Combined statistical analysis of the two years data reveals that N rates and timings of N application significantly affected total weight plant^{-1}. Increase in N rates enhanced total weight plant^{-1} with the highest N rate of 180 kg ha^{-1} producing the maximum weight of 212.5 g plant^{-1}, while the minimum weight of 183.2 g plant^{-1}was recorded in plots which received the lowest rate of N. Heaviest plants (214.1 g plant^{-1}) were observed in those plots to which N was applied in five unequal splits (S6), while minimum plant weight (174.8 g plant^{-1}) was produced with application of N in two equal splits. Total weight plant^{-1} of maize increased with increase in N rates and timings of N application and slightly decreased with increase in plant density. The heavier total weight per plant with application of higher N rate might be due to greater assimilates formation as a result of increase in leaf area. These results are in confirmation with those of Toler et al. (1999) who reported that in high density of maize crop decreases leaf area and leaf biomass plant^{-1} which decrease stem biomass plant^{-1}. The greater total weight may have resulted from greater partitioning of assimilates to stem due the increase in the availability of N to maize. Similar results were reported by Pandey et al. (2000) and Turgut (2000) that maize dry matter production in maize increased due to high rates of N application to maize.

Number of seeds plant^{-1}

Data pertaining to number of seeds ear^{-1} of maize as affected by years, plant density, rate and timing of N are shown in Table 1. Combined statistical analysis of the data revealed that years, N rate and the split application for N significantly influenced number of seeds ear^{-1}. Maize produced significantly more seeds in 2003 than in 2002. In 2003 there was more rain fall during grain filling stage of maize that might have increased assimilates partitioning to ear and thus may have increased seeds ear^{-1}. Plants density had no significant effect on number of seeds per plant. However, maize produced more seeds per plant in low density than high density plots. Increase in plant density increase inter plant competition in maize which may have resulted in less number of seeds ear^{-1}, while in thin population inter plant competition was less which may have resulted in higher number of seeds ear$^{-1.}$ Similar results were reported by Singh et al. (1997) that number of seeds per ear decreases with increase in plant density. Number of seeds ear^{-1} showed positive relationship with N rates. Increasing N rate increased number of seeds ear^{-1} from a minimum of 362 (60 kg ha^{-1}) to a maximum of 411 (180 kg ha^{-1}). Number of seeds per ear increased with increasing the number of splits for N application from a minimum of 349 seeds ear^{-1} with two split application of N to a maximum of 422 seeds per ear when N was applied in five unequal splits (S6). Increasing N rate and splits for N increased the reproductive growth period of maize so more photo assimilates were partitioned to seed during grain filling stage which decreased tip fill and increased number of seeds ear^{-1}. The greater number of seeds ear^{-1} with higher N rate may have resulted from greater assimilates as a result of larger leaf area and more photosynthesis during grain filling. The increase in number of seeds ear^{-1} with increase in the number of split may be due to comparatively more assimilates availability at the time of grain filling which may have resulted in formation of more number of seeds ear^{-1}. These results are in conformity with those of Stone et al. (1998), Soliman et al. (1999), Andrade et al. (1999), Akbar et al. (1999) and Turgut (2000).

Grain yield plant^{-1}

Combined statistical analysis of the data given in Table 1 reveals that year, N rates and timings of N application significantly affected grain yield per plant. Grain yield plant^{-1} was greater in 2003 than 2002. The variation in the yield in different years is due to the fluctuation in the rainfall. The lower yield in 2002 than 2003 might be due to shortage of rain fall in the early growth of maize in 2002 than in 2003. Grain yield plant^{-1} showed positive relationship with the increase in N rates and number of split application. The highest grain yield of 99 g plant^{-1} was produced by plots to which the maximum rate of 180 kg N ha^{-1} was applied, while the lowest yield of 86 g ear^{-1} was recorded in the plots which received the minimum rate of 60 kg N ha^{-1}. Increasing N rate increased grain yield significantly. This increase in yield might be due to the decrease in barrenness, increase in seeds ear^{-1} and increase in 1000 seeds weight. These results are in close conformity with the results obtained by Purcino et al. (2000); Pandey et al. (1999); Gaurker and Bharad (1998); Anjum et al. (1992) and Mariga et al. (2000). N applied in five unequal splits (S6) gave the highest yield of 102 g plant^{-1}, followed by yield of 98 g ear^{-1} in the plots which received N in five equal splits (S5), while minimum grain yield of 82 g plant^{-1} was recorded in plots to which N was applied only at two splits. These results are in confirmation with those of Mariga et al. (2000), Gomachadze (1999), and Scharf et al. (2002). Plant density had no significant affect on grain yield plant^{-1} however it ranged between 92 g in high density plots and 95 g plant^{-1} in low density plots. The decrease in the yield per plant in high plant density might be due to the strong competition of plants in high density than in the low density. These results are in confirmation with those of Chiesa et al. (2000) that highest density in maize decreased grain yield. In high density plots grain yield plant^{-1}decreased but grain yield ha^{-1} increased (unpublished data). Similar results were reported by Toller et al. (1999); Yogananda et al. (1999); Modarres et al. (1998); Gaurker and Bharad (1998); Anjum et al. (1992) and Mariga et al. (2000) that grain yield increased in high than in low density plots.

Table 1. Partitioning of dry matter and grain yield potential in maize as affected by plant density, rate and timings of N application

Years	Leaf weight (g)	Stem weight (g)	Ear weight (g)	Tassel weight (g)	Ear sheath Weight (g)	Total plant weight (g)	Seeds per plant (g)	Yield per plant (g)
2002	23.4	48.7a	105.1b	4.1	7.9	183.7	378	88b
2003	25.8	41.3b	124.8a	4.2	8.1	204.1	395	97a
LSD for years ($P \leq 0.05$)	ns	2.29	14.05	ns	ns	ns	ns	5.21
Number of Plants ha^{-1}								
P1 = 60000	25.0	45.3	115.5	4.1	7.9	197.7	388	95
P2 = 100000	24.2	44.8	114.4	4.1	8.2	195.5	385	92
LSD for plant density ($P \leq 0.05$)	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen rates (kg ha^{-1})								
N1 = 60 (50% less than recom. rate)	22.6c	40.8c	108.3	4.1	7.5c	183.3c	362c	86c
N2 = 120 (Recommended rate)	24.5b	43.8b	113.7	4.1	8.0b	194.1b	386b	92b
N3 = 180 (50% greater than recom. rate)	26.7a	50.4a	122.9	4.1	8.4a	212.5a	411a	99a
LSD for N rates ($P \leq$ 0.05	1.19	1.96	4.38	ns	0.43	5.13	10.26	3.27
Timings of N Application (S)								
S1 = Two splits (50-50%)	20.9c	40.5d	101.4d	4.1	7.8	174.8e	349e	82d
S2 = Three splits (50-25-25%)	22.5b	40.7d	106.9c	4.1	7.9	182.0d	362d	84d
S3 = Three splits (33-33-33%)	23.8b	44.2c	115.6b	4.2	8.0	195.8c	382c	92c
S4 = Four splits (25-25-25-25%)	26.4a	46.8b	120.3a	4.2	7.8	205.6b	397b	96bc
S5 = Five splits (20-20-20-20-20%)	26.8a	47.6b	120.7a	4.1	8.2	207.4b	406b	98ab
S6 = Five splits (8-17-25-33-17%)	27.0a	50.2a	124.7a	4.1	8.2	214.1a	422a	102a
LSD for N timings ($P \leq 0.05$)	1.36	2.51	4.64	ns	ns	5.95	11.06	4.37

Acknowledgements: I am very much thankful to Department of Agronomy, NWFP Agricultural University, Peshawar-Pakistan, for providing facilities for conducting this research work.

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Appendix I. Physiochemical soil (30 cm depth) properties of the Agriculture Research Farm, NWFP Agricultural University, Peshawar

S.No.	Soil Property	Level/Type
1	Textural Class	Clay Loam
2	Calcareousness	Highly Calcareous
3	pH	8.2
4	$CaCo_3$	10.37
5	Organic Matter	0.87 %
6	Available K_2o	121 ppm
7	Available P_2O_5	6.57 ppm
8	Total Soluble Salts (TSS)	0.058 %
9	Electrical Conductivity	0.90 m. mhos cm^{-1}

Appendix II. Meteorological data at the Agriculture Research Farm for both years during the experiment

Name of Climatic Parameter	2002			2003		
	July	Aug.	Sep.	July	Aug.	Sep.
Total Precipitation (mm)	1.0	116.6	14.9	73.2	51.6	45.2
Number of Precipitation Days	03	08	05	11	12	04
Mean Max. Temperature (^oC)	39.7	34.7	33.0	37.0	35.6	34.3
Mean Min. Temperature (^oC)	26.0	25.5	21.3	26.5	25.0	23.4
Absolute Max. Temperature (^oC)	43.6	40.6	34.6	42.2	38.5	38.4
Absolute Min. Temperature (^oC)	22.8	15.6	17.1	23.9	22.5	15.5
Mean R.H. (%) 1200 GMT	41	64	58	57	60	57
Mean Daily R. Humidity (%)	54	75	72	69	73	72
Days with Max. Temp. $\geq 35\ ^oC$	31	15	NIL	26	21	17
Days with Max. Temp. $\geq 40\ ^oC$	14	02	NIL	04	NIL	NIL
Pan Evaporation (mm)	174.0	97.2	85.2	143	112.8	82.1
Total Sunshine hours	276.8	191.4	240.1	264.4	241.1	197.0