Nitrogen Requirements of Fresh-market Tomatoes on Hairy Vetch and Black Polyethylene Mulch

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Abstract. A 3-year experiment was conducted to determine the optimum fertilizer N requirements of fresh-market tomato (*Lycopersicon esculentum* Mill.) 'Sunbeam' grown on a hairy vetch (*Vicia villosa* Roth.) or black polyethylene mulch. In 1993 and 1994, four rates of fertilizer N (0, 56, 112, and 168 kg-ha⁻¹) as water-soluble NH₄NO₃ were applied in 14 equal applications through the trickle irrigation system starting 1 week after planting. Four additional rates (224, 280, 336, and 392 kg-ha⁻¹) were applied in 1995 to assess the plant response to supra-optimal levels of N. Hairy vetch produced 3.3–4.5 t-ha⁻¹ of above-ground biomass and a total N content of 126–169 kg-ha⁻¹ in the above-ground biomass. Leaf N content at 7 weeks after transplanting of tomatoes correlated positively with yield from black polyethylene but did not correlate with yield from the hairy vetch plots where leaf N content was optimal at all N rates. Predicted tomato yields were higher for the hairy vetch than for the black polyethylene treatment at all applied N rates in all years. Tomatoes grown in black polyethylene required N at 130 to 144 kg-ha⁻¹ to achieve yields equivalent to those grown following unfertilized hairy vetch. Tomato yield increased in response to applied N in both mulches in all 3 years; optimum N rates of 89 and 190 kg-ha⁻¹ in hairy vetch and black polyethylene, respectively, were predicted by a linear plateau model, and 124 and 295 kg-ha⁻¹ by a quadratic plateau model. The linear plateau model is recommended because it would allow less N to become available for runoff and leaching.

Fresh-market tomatoes are conventionally grown in the field using raised beds, polyethylene mulches, and trickle irrigation (Hartz, 1993). Under this system, N requirements, the type of N source, and the method and frequency of application are well established. The recommendation in the mid-Atlantic states is to incorporate N at 45 kg-ha⁻¹ into the soil before planting, and to apply additional soluble N at 45 kg-ha⁻¹ through the trickle irrigation system split into three equal applications during the growing season, making a total of 90 kg-ha⁻¹ (Rutgers Cooperative Extension, 1995). In California, tomato growers typically apply N at 135 kg-ha⁻¹ to assure high yields (Lorenz and Maynard 1988), and in southwest and west-central Florida, growers apply N at 230–

560 kg-ha⁻¹ per season (Csizinszky and Schuster, 1982).

Wien and Minotti (1988) found that N at 84 kg-ha⁻¹ with clear polyethylene mulch increased total yield, and 168 kg-ha⁻¹ decreased early yield in 1 out of 2 years compared to no N. Broadbent et al. (1980) and Doss et al. (1975) found no significant increase in tomato yield with N above 65 kg-ha⁻¹, whereas Mason and Wilcox (1982) noted yield increases up to 336 kg-ha⁻¹.

Even under the most efficient method of N delivery through the trickle irrigation system, N recovery by the tomato plant from fertilizer N is low. Hills et al. (1983) reported that recovery of labeled N from fertilizer, applied as ammonium sulfate, was 27% for tomato compared to 57% for corn (*Zea mays* L.). Because of this low efficiency of N fertilizer recovery by the tomato plant, many growers apply N in excess of recommended rates in order to maximize yield. Supra-optimal N levels increase soil salt content and production cost (Csizinszky and Schuster, 1982). Furthermore, plant use efficiency decreases and more nitrate N is likely to become available for

runoff and leaching (Doss et al., 1975). Nationally, N from commercial fertilizers and animal manures has been one of the major contaminants of surface and groundwater in 17 states in the United States (Hallberg, 1987; Meisinger et al., 1991; National Research Council, 1989).

Alternative production systems for tomatoes, which utilize legume cover crops and reduced use of commercial fertilizer, have recently been introduced (Abdul-Baki and Teasdale, 1993; Abdul-Baki et al., 1996). The cover crops utilize N leftover in the soil from the previous crop and fix N. Both intercepted and fixed N are converted into biomass and become available to the subsequent vegetable crop. The overall N balance in this production system is more complicated and less explored than that in production systems that depend mainly on N from synthetic fertilizers. In particular, the N contribution by the cover crop to the subsequent vegetable crop needs to be evaluated.

Published information on legume cover crops suggests that they can reduce leaching losses (Holderbaum et al., 1990) and make a significant contribution to the N nutrition of the subsequent crop (La Rue and Patterson, 1981; Stivers and Shennan, 1991). Winter annual cover crops, when used with no tillage, reduce soil erosion and loss of nutrients from the upper layer of the soil profile (Decker et al., 1994; Langdale and Leonard, 1983; Shipley et al., 1992). Hairy vetch top growth has been reported to contain N at up to 350 kg-ha⁻¹ (Holderbaum et al., 1990). However, legume N contribution to succeeding nonlegume crops is variable and depends on many factors, including the N status of the soil, dry matter yield, and N concentration of the legume cover crop (Holderbaum et al., 1990). Tillage and environmental conditions further affect N availability by controlling residue decomposition rate.

The purpose of our investigation was to determine N requirements by fresh-market field tomatoes in a no-tillage system following a hairy vetch cover crop and compare it to the conventional production system in polyethylene mulch.

Materials and Methods

The experiments were conducted for 3 years (1993–95) at the farm of the Beltsville Agricultural Research Center, Beltsville, Md., on a Woodstown sandy loam soil (siliceous, mesic, Paraquic Normudults, Ultisol) with 2% slope. The two mulch treatments, each 36.6 m long and 12.2 m wide, were hairy vetch and black polyethylene. They were arranged in a split-plot design, with mulch as a whole plot and N rate as subplot. Whole plots were randomized within three blocks with two 15-plant harvest sections each 7.2 m long and 1.5 m wide per N treatment within each whole plot in 1993 and 1994. Whole plots were randomized within four blocks with one 15-plant harvest section per N treatment in 1995. Nitrogen rates were 0, 56, 112, and 169 kg-ha⁻¹ in 1993 and 1994. Four additional rates were added in 1995: 225, 281, 337, and 393 kg-ha⁻¹.

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Seed source and seedling production. Fresh-market 'Sunbeam' tomato seeds were sown in a greenhouse in 128-cell flats (cell size 4 × 4 × 6 cm) filled with Jiffy Mix Plus (Jiffy Products of America, Batavia, Ill.), a mixture of 50% peat : 50% horticultural grade vermiculite (w/w) supplemented with starter fertilizer. The seedlings were held 4 weeks in the greenhouse and 1 week in the cold frame before transplanting to the field. Dates for various operations, including starting the seeds, transferring to the cold frame, and transplanting, were recorded (Table 1).

Field preparation. Soil tests conducted each year at field preparation time revealed that no P or K was needed in 1993 and 1994. In 1995, K at 92 kg-ha⁻¹ was broadcast according to soil tests over the entire field and disked with the soil to 30-cm depth at the time the beds were prepared. The field was plowed, disked, and beds 15 cm high and 1 m wide on the surface were formed. The hairy vetch seed was sown at 50 kg-ha⁻¹ using a Brillion seeder (Brillion Iron Work, Brillion, Wis.). The plots received no water, herbicide, fertilizer, or any other treatment until they were mowed with a high speed flail mower (Hesston Corp., Oregon, Ill.) 3–5 cm above the bed surface. Beds for the black polyethylene mulch treatment were prepared and the trickle irrigation lines (Turbo tape, San Diego), with 30 cm emitter spacing (350 L-h⁻¹ per 100-m line) and black polyethylene mulch films (2.5 × 10⁻² mm thick) were laid shortly before transplanting (Table 1). The trickle irrigation lines were buried 5 cm deep in the soil and 6–8 cm away from the plants, with emission pores upward.

Planting. The 5-week-old tomato seedlings were planted in the field at 56 cm within the row around mid-May of each year (Table 1) using a Holland minimum tillage planter (Holland Co., Holland, Mich.). Liquid starter solution fertilizer (Peters starter fertilizer 9N–19.6P–12.5K at 37 g-L⁻¹ water) was applied at transplanting. The trickle irrigation lines in the hairy vetch mulch were laid on the mulch surface 6 cm away from the plants with the emission pores downward, and held in position with U-shaped wires spaced at 5-m intervals. All plants were staked 2 weeks after planting and tied three times.

Watering and fertilizing. Water was delivered through the trickle irrigation system generally every other day to avoid moisture stress. An on/off valve was installed on each trickle line at the point of connection with the submain to deliver fertilizer and water to individual treatments without losses or spills to adjacent beds.

In addition to the starter fertilizer applied at transplanting, additional N as NH₄NO₃ (33.5% N) was applied through the trickle irrigation system in equal portions at 14 weekly intervals starting 1 week after field planting.

The integrated pest management (IPM) system, adopted by the Univ. of Maryland, College Park, was implemented for pest control. Colorado potato beetles were controlled using Bt-based insecticides. Fixed copper [77% Cu(OH)₂] was applied once at the fruit-set stage to a few selected plants that exhibited

mild symptoms resembling stem canker, although the presence of canker was not confirmed. Tetrachloroisophthalonitrile (chlorothalonil) was applied weekly to control fungal diseases, using manufacturer's suggested rates, starting when early fruit diameter reached 1 cm. Weeds were controlled by one application of 4-amino-1,1-dimethylethyl-3-(methylthio)-1,2,4-triazin-4(4H)-one (metribuzin) at 0.56 kg-ha⁻¹ between the beds in the polyethylene mulch treatment and over the whole area in the vetch mulch beds 3 weeks after planting.

Yield determination. Fruits from 15 plants (7.84 m) in each subplot were harvested every 5–6 days at the breaker to pink stages. Nonmarketable fruit, including damaged, deformed and small fruits, were eliminated before weighing. The length of the harvest period and number of harvests per year varied from 5 to 12 (Table 1).

Biomass yield and N concentration of hairy vetch. Aboveground yield of hairy vetch was determined just before mowing in four 1-m² randomly selected locations outside of the plot area. Grass clippers were used to cut the plants as close to the bed surface as possible, avoiding removal of any soil. Hairy vetch samples were dried at 70 °C in a forced-air oven for determining dry matter yield, ground to pass a 0.6-mm sieve, and then analyzed for total Kjeldahl N concentration (Baker et al., 1964). Total N content was calculated by multiplying N concentration by dry matter yield.

Nutrient analysis of tomato leaves. Elemental concentrations of tomato leaves were determined every year at 7 weeks after field planting. This stage of plant development coincided with rapid fruit growth and high demand for nutrients. Ten uppermost fully developed whole leaves of similar physiological age were taken from each of two replications representing each N level. Leaves were immediately taken to the laboratory, washed in 0.1% sodium lauryl sulfate solution, rinsed several times with deionized water, forced-air dried at 70 °C overnight, and ground to pass 0.6-mm sieve opening. Analysis of P, K, Ca, Mg, and B was performed by plasma emission spectroscopy and total N by Kjeldahl (Baker et al., 1964).

Statistical analysis. Analysis of covariance was conducted on yield and leaf N data with block and mulch treated as class variables and N rate as a regression variable (SAS, version 6.10). The F value for experimental error did not exceed 1 in 1993 and 1994; therefore, sampling error and experimental error for these years were pooled.

Results

Biomass yield and N concentration of hairy vetch. Biomass yield and N concentration (Table 2) of hairy vetch were in the ranges reported by others (Hargrove and Frye, 1987; Holderbaum et al., 1990; Shipley et al., 1992). A uniform mulch coverage of the bed area was achieved in all years. Our results confirm the well established adaptability of hairy vetch to the Beltsville area.

Yield response to applied N and mulch. Yield increased in response to applied N in both mulches in all years (Table 3, Figs. 1–3). The yield increase was linear in 1993 and 1994 but quadratic in 1995. The lower range of N rates used in 1993 and 1994 did not permit expression of a curvilinear response. Comparisons between main effects of mulches were insensitive because of the low degrees of freedom associated with using the block × mulch error term (Table 3). Nonetheless, models consistently showed higher yield in hairy vetch than black polyethylene at all N rates in all years. Mulch and N rate interacted significantly on yield in 1993, resulting in greater response to applied N in black polyethylene than in hairy vetch (Table 3, Fig. 1). Tomato yields in black polyethylene were low at all N rates in 1994 because of severe foliar infection by *Alternaria solani* (Ell. and G. Martin) Sor., incitant of early blight. No infection was noted on plants following hairy vetch.

Response of leaf N to mulch and applied N. Nitrogen concentration of tomato leaves 7 weeks after field planting was consistently higher with hairy vetch than with black polyethylene at all rates of applied N in 1993 and 1995 but not in 1994 (Figs. 1–3). The effect of mulch on leaf N concentration was not significant.

Table 1. Dates of main operations for tomato production systems.

Operation	Growing season		
	1993	1994	1995
Preparing beds and planting hairy vetch seed ²	28 Sept.	24 Sept.	14 Sept.
Preparing beds for black polyethylene treatment	9 May	13 May	10 May
Mowing hairy vetch	9 May	16 May	13 May
Starting tomato seedling in greenhouse	6 Apr.	11 Apr.	11 Apr.
Transplanting tomatoes	11 May	17 May	13 May
First harvest	15 July	29 July	28 July
Last harvest	9 Sept.	11 Oct.	24 Aug.
Number of harvests	10	12	5

²Dates are for year preceeding the growing season.

Table 2. Hairy vetch biomass and nitrogen content (dry mass basis) at the time of mowing.

Year	Dry mass (kg-ha ⁻¹)	N content	
		N (%)	Total (kg-ha ⁻¹)
1993	3300	3.82	126
1994	4040	3.44	139
1995	4500	3.76	169

cant in 1994, probably because of the insensitivity associated with the few degrees of freedom for this test. There was a slight but significant increase in leaf N concentration in response to applied N in 1993 and 1995. Tomato leaf N with black polyethylene with no applied N averaged 3.0% and never exceeded 3.8% at maximum N rates. Tomato leaf N with hairy vetch with no applied N was consistently higher than that at any rate of N applied to plants grown with black polyethylene.

Yield response to leaf N concentration. Marketable yield of plants grown on black polyethylene increased linearly with the increase in percent leaf N resulting from fertilizer N application. In contrast, there was no significant relationship between yield and leaf N content for plants grown in hairy vetch mulch (Fig. 4). Presumably, hairy vetch decomposition supplied sufficient N (potentially 126 to 169 kg·ha⁻¹) that leaf N was saturated at all applied N rates. Leaf concentrations of all other macro- and micronutrients, with few exceptions, were similar in both mulches and were at the sufficiency levels (data not reported) for tomatoes as recommended by Piggott (1986).

Yield data from the 3 years were combined to provide an overall estimate of yield response to N rate (Fig. 5). Linear plateau, quadratic plateau, and quadratic models were fit to these data (Table 4). The two plateau models fit data for hairy vetch plots better than the quadratic model based on comparison of *R*² values. Both plateau models also predicted lower maximum yields and lower optimal N rates than the quadratic model for the hairy vetch plots. Cerrato and Blackmer (1990) and Bullock and Bullock (1994) reported similar results by a comparison of these models for fitting corn yields to applied N rates.

All three models fit similarly to the data for black polyethylene (Table 4). The linear plateau model predicted a lower optimal N rate than either of the quadratic models. All models predicted an N equivalence rate similar to that for the unfertilized hairy vetch treatment.

Discussion

Dry matter production is more important than N concentration in determining the N contribution of the cover crop to the vegetable crop. In spite of fluctuations in the growing conditions from year to year, hairy vetch produced an average of 3950 kg·ha⁻¹ dry matter and 145 kg·ha⁻¹ N in top growth alone. The C : N is relatively low (≈8) compared to other legumes and grasses and decomposition rate is rapid whether mowed or chemically killed (Somda et al., 1991).

Various models provided a reasonable fit to the yield data in these experiments (Table 4). The linear plateau model gave the most conservative estimate of optimum N rate. According to this model, the minimum N rates required to achieve maximum yields were 89 and 190 kg·ha⁻¹ for hairy vetch and black polyethylene, respectively (Fig. 5). By substituting these optimum values for the linear plateau model into the other models, the con-

sequences of following this recommendation and being wrong can be calculated. Computations show that yield losses would range from 1% to 4% of maximum yield if the linear plateau model were followed incorrectly. However, the consequences of following the quadratic plateau model when the linear plateau model would be correct would be wasting N at 35 and 105 kg·ha⁻¹ for hairy vetch and black polyethylene, respectively. The choice

of model would depend on the relative value placed on maximizing yield vs. wasting money and reducing potential N losses to the environment.

The quadratic models predict a diminishing return as N rate approaches optimum and, therefore, the economic optimum would be reached before the biological optimum N rate. However, the high value of the fresh-market tomato minimizes this effect. For example,

Table 3. Analysis of covariance of tomato yield and leaf nitrogen content using mulch as class variable and nitrogen rate as regression variable.

Source	<i>P</i> > <i>F</i>		
	1993	1994	1995
<i>Yield</i>			
Mulch ²	0.1297	0.0071**	0.3437
N	0.0001**	0.0001**	0.0004**
N × N ²	NS	NS	0.0093**
N × Mulch	0.0001**	0.8918	0.8267
N × N × Mulch ²	NS	NS	0.9340
<i>Leaf N concentration</i>			
Mulch ²	0.0138*	0.2724	0.0042**
N	0.0248*	0.1819	0.0001**
N × N ²	NS	NS	NS
N × Mulch	0.1269	0.2871	0.0115*
N × N × Mulch ²	NS	NS	NS

²F-value determined using Block × Mulch as the error term.

²These quadratic terms were included in the initial model. When these terms were nonsignificant (NS), the model was rerun without them.

NS, *, **Nonsignificant or significant at *P* ≤ 0.05 and 0.01, respectively.

Fig. 1. Response of tomato marketable yield and leaf N content at 7 weeks after transplanting to rate of applied fertilizer N when grown with a hairy vetch (solid circles and line) or black polyethylene (open circles and dashed line) mulch in 1993. Regression equations are $Y = 70.6 + 0.0488X$ ($R^2 = 0.57$) and $Y = 43.0 + 0.171X$ ($R^2 = 0.84$) for vetch and polyethylene, respectively, where Y = yield and X = N rate. Regression equations are $Y = 4.40 + 0.000780X$ ($R^2 = 0.16$) and $Y = 2.79 + 0.00368X$ ($R^2 = 0.51$) for vetch and polyethylene, respectively, where Y = leaf N and X = N rate.

Fig. 2. Response of tomato marketable yield and leaf N content at 7 weeks after transplanting to rate of applied fertilizer N when grown with a hairy vetch (solid circles and line) or black polyethylene (open circles and dashed line) mulch in 1994. Regression equations are $Y = 62.4 + 0.0584X$ ($R^2 = 0.49$) and $Y = 21.6 + 0.0618X$ ($R^2 = 0.60$) for vetch and polyethylene, respectively, where Y = yield and X = N rate. There was no significant regression of leaf N on N rate in 1994.

Fig. 3. Response of tomato marketable yield and leaf N content at 7 weeks after transplanting to rate of applied fertilizer N when grown with a hairy vetch (solid circles and line) or black polyethylene (open circles and dashed line) mulch in 1995. Regression equations are $Y = 65.2 + 0.125X - 0.000238X^2$ ($R^2 = 0.44$) and $Y = 55.4 + 0.141X - 0.000224X^2$ ($R^2 = 0.52$) for vetch and polyethylene, respectively, where Y = yield and X = N rate. Regression equations are $Y = 4.40 + 0.000649X$ ($R^2 = 0.46$) and $Y = 3.04 + 0.00207X$ ($R^2 = 0.44$) for vetch and polyethylene, respectively, where Y = leaf N and X = N rate.

Kelly et al. (1995) found a value of \$500/t to be typical for fresh-market tomatoes. Even at a relatively expensive price of \$1.00/kg of N, economic optimum N rates would only be reduced by 3 to 5 kg·ha⁻¹.

Fresh-market tomatoes respond to increasing fertilizer N even when grown in a hairy vetch mulch (Fig. 5). Tomatoes grown with black polyethylene had a higher N requirement and a greater penalty for elimination of N than those grown in hairy vetch. Nitrogen at 130 to 144 kg·ha⁻¹ was required with black polyethylene to give yields equivalent to plants in unfertilized hairy vetch (Table 4). Moreover, maximum yield in hairy vetch was higher than that in black polyethylene, suggesting that hairy vetch contributes more than N to tomato production. A similar response has been documented in corn (Decker et al., 1994; McVay et al., 1989). Other factors that could contribute to a higher maximum yield in hairy vetch include soil enrichment with organic matter that improves soil physical properties (McVay et al., 1989). Contribution of hairy vetch mulch to soil moisture retention probably is not a factor in these experiments because soil moisture was maintained at optimal levels in all treatments through trickle irrigation.

Fig. 4. Relationship between tomato marketable yield and leaf N content at 7 weeks after transplanting with a hairy vetch (solid circles and line) or black polyethylene (open circles and dashed line) mulch over all years. Yield was converted to a percentage of the mean yield of the highest yielding treatment in each year before analysis. The 1994 black polyethylene data was eliminated because of severe disease pressure in these treatments. Regression equations are $Y = 85.0 + 1.76X$ ($R^2 = 0.01$) and $Y = -24.0 + 31.4X$ ($R^2 = 0.76$) for vetch and polyethylene, respectively, where Y = yield and X = leaf N.

Hills et al. (1983) have shown that tomatoes have poor N-use efficiency. In their study, tomatoes recovered only 27% of labeled N from fertilizers. The N rates shown to provide maximum yields in our study could lead to significant losses to the environment. Hairy vetch reduces the required applied N rate relative to the black polyethylene system, but similar amounts of N are potentially lost from a hairy vetch mulch and also could lead to contamination of the environment (McCracken et al., 1994). Despite similarities in amount of N potentially lost, we hypothesize that tomato roots would recover N more efficiently from the hairy vetch than the black polyethylene system. Our research has shown that tomato roots are uniformly distributed across the tomato bed (Teasdale and Abdul-Baki, 1995) and would be more likely to intercept N decomposing from vetch residue distributed uniformly across the bed surface than N released from a narrow band under the drip irrigation line. More research is needed to investigate the relative loss of N from hairy vetch residue vs. fertilizer.

In conclusion, we presented new information in support of the hairy vetch mulch system. Hairy vetch has been shown to provide consistently high yields and profits of fresh-market tomatoes (Abdul-Baki and Teasdale, 1993; Abdul-Baki et al., 1996; Kelly et al.,

1995). One of the most attractive features of using hairy vetch as a mulch is its capability of supplying high quantities of N and biomass. About 85%–90% of the N in the vetch plant is in the top growth (Mitchell and Teel, 1977). The remaining 15% is in the roots and remains in the soil profile. The ability of the hairy vetch to provide the tomato plant with most or all of its N requirement depends on factors such as the amount of dry matter produced, N concentration, C : N ratio, and other environmental conditions which affect residue degradation and N release. Generally, fluctuations in dry matter yields are larger than those in N concentration and depend on factors such as date of seeding the hairy vetch, rainfall, temperature during germination and field establishment, and date of terminating the cover crop.

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Fig. 5. Response of tomato marketable yield to rate of applied fertilizer N when grown with a hairy vetch (solid circles and line) or black polyethylene (open circles and dashed line) mulch over all years. Yield was converted to a percentage of the mean yield of the highest yielding treatment in each year before analysis. The data for 1994 black polyethylene were eliminated because of severe disease pressure. See Table 4 for model details.

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Table 4. Models fitted to percentage yield means from all years as a function of applied N rate.

Mulch	Model	R ²	Optimum N rate (kg·ha ⁻¹)	Maximum yield (%)	N equivalent to unfertilized vetch (kg·ha ⁻¹)
Hairy vetch	Linear plateau				
	Y = 82.8 + 0.149X if X < 88.9				
	Y = 96.1 if X ≥ 88.9	0.52	89	96	---
	Quadratic plateau				
Black poly	if X < 124 Y = 82.6 + 0.215X - 0.000867X ²	0.52	124	96	---
	Y = 96.0 if X ≥ 124				
	Quadratic				
	Y = 84.9 + 0.115X - 0.000252X ²	0.40	228	98	---
Black poly	Linear plateau				
	Y = 62.5 + 0.152X if X < 190				
	Y = 91.4 if X ≥ 190	0.81	190	91	134
	Quadratic plateau				
	if X < 295 Y = 61.5 + 0.208X - 0.000353X ²	0.82	295	92	130
	Y = 92.2 if X ≥ 295				
	Quadratic				
	Y = 60.9 + 0.222X - 0.000385X ²	0.84	288	93	144

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