USE OF FLAME AS A MEANS TO CONTROL WEEDS IN CORN PRODUCTION

by

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INTRODUCTION

Weeds are an ancient companion of man. Ever since he learned to till the soil, weeds have plagued his efforts to produce crops. Even before this weeds were a problem where his animals over-grazed the virgin vegetation. Most weeds grow in areas that have been disturbed by man--pastures, cultivated fields, roadsides, railroad embankments, city lots, and neglected lawns and gardens. They do not occur in virgin woods and prairies or other untouched areas. The common broad leaved plantain was known to the American Indian as "Whiteman's foot" because it grew wherever the white man had passed.

The state we know as Kansas was once devoted to native vegetation and inhabited by wild animals and Indians. There was a scarcity of weeds then, according to early observers, and those that are indigenous did not make much headway in competition with the luxuriant and hardy grasses that nature so beneficiently provided. When the white man moved in and sod was broken, native weeds found planted crops less resistant to their spread. Under the new and strange conditions of the plains country, the pioneers were engrossed in learning of new crops and methods best adapted to the soils and climate. Weeds were among the least of their problems. Moreover, early day facilities and practices were not so conducive to the dissemination of weeds. Modern methods of transportation and mechanized agriculture have been largely responsible for the rapid spread of weeds in more recent years (11).

The economic importance of weeds is far greater than many people realize. Weed losses on American farms are estimated as high as five billion dollars annually (23). They are more costly than plant diseases and insect pests combined and are classified as our greatest single agricultural loss. Table 1 presents the several types of agricultural losses.

Table 1. Annual agricultural losses (31).

	Annual losses (x 1000)	Per cent of total
Soil losses	$ 1,512,000	13.6
Plant insect losses	1,605,727	9.6
Plant disease losses	2,912,601	26.3
Livestock disease losses	1,847,904	16.7
Weed losses	3,747,036	33.8
	$11,625,268	100.0

Weeds compete with crops for water, nutrients and light. They increase the cost of labor and equipment and reduce the quality of farm products. They clog harvesting equipment and prevent recovery of full harvest. Weed control is as old as agriculture itself and is one of the most expensive steps in crop production. In a way of life that has learned to control almost everything, it is of scientific interest that man has done so little to control this persistant and age old problem.

Man's fight against weeds has been slow. Like almost every phase of agriculture, very little improvement was made in methods and techniques until the 19th century. Most of the real advancements have come during the past fifty years. Slowly man has learned to mechanize and to use power in his fight. First, he replaced his fingers with a sharpened stick, then came the hoe, which in turn was replaced by the cultivator and plow. The suggestion of planting crops in rows to permit "horse hoeing" comes from Jethro Tull in 1731, the author of "Horse Hoeing Husbandry". He was also among the first to use the word "weed" in its present spelling and meaning (15). Man has also used mowing, burning, smother crops and crop rotations in an effort to control the growth and spread of weeds.

Chemical Weed Control

About a century ago Europeans, who were using copper salts on grain to control fungus diseases, noticed that these chemicals killed certain broad leaved weeds but did not injure the grain. Salt was also being used on cut stubs of thistles to prevent their regrowth. However, it was not until several years later that any real development in the control of weeds by the use of chemicals was made. The following accomplishments are worth noting.

1. The discovery of selective herbicides about 1900.
2. The discovery that 2,4-D (1944) kills some weeds but not grasses.
3. The development of low volume application techniques.
4. The development (1947) of effective pre-emergence chemicals.

These new organic chemicals kill weeds in a different way from such inorganic compounds as iron sulfate and sodium arsenate which scorch the weeds and kill only the parts they touch. Leaves, stems and roots absorb these new chemicals and once inside susceptible plants move to all other parts, killing the entire plant even though at first it touches only a limited area.

Following the development of 2,4-D there has been a phenomenal growth in production of selective herbicides by the United States chemical industry. Several dozen effective and safe organic weed killers are now available to farmers and homeowners. Among these are 2,4,5-T, MCPA, silvex (phenoxy compounds); DNBP (a substituted phenol); TBA (a substituted benzoic acid); IPC, CIPC, EPTC (carbonates); monuron, diuron, fenuron (substituted phenylureas); TCA, dalpon, simozine and atrazine (trizines) and many more are being tested. Some may be applied in either spray or granular form. Some are to be applied before the crop emerges and others on the growing weeds.

Chemical weed killers are used on more than fifty-three million acres of cropland annually. They are also effective against weeds in pastures, rangeland, drainage ditches, irrigation systems, lawns, gardens, railway and highway right of ways and many others. Chemical weed control methods are generally an efficient way to control weeds, but they are often-times costly operations and require precision and careful application if they are to be effective.

Flame Cultivation

About the same time that chemical weed control was enjoying this tremendous growth, another method of control was being tried and developed. Selective burning, a technique of applying a hot blast of flame to weed infested crops, was started in the late 1930's. It has met with varying degrees of success but until the past few years has been limited mainly to cotton production. Flame cultivation, as it is popularly called, is presently gaining greater interest and attention. It is being tried on many different crops and used in expanded areas of the country.

The principle of flame weeding is basically the careful application of fire to kill weeds without injurying the crop plants. The first flame cultivator was a rather cumbersome, sulky-type implement consisting of a gasoline engine, an air compressor, cone-shaped burners and an assortment of valves, fuel lines and other accessories. The flame was produced from a mixture of fuel oil and air. The compressor provided pressure to develop higher temperatures and effective flame application (29). Improvements in the early 1940's consisted of mounting the machine on the tractor and utilizing the power-takeoff to operate the compressor.

Flame cultivation, as we know it today, began with the introduction of LP-gases (butane and propane) as fuels in 1945 (17). The round, Barr-type LP-gas burner was also introduced at that time and was subsequently adopted by most manufacturers. A self-energizing burner which utilized the liquid petroleum fuel was also developed and used on some machines. Significant developments in 1948 and 1949 were largely responsible for the revival of interest in flame cultivation in much of the cotton producing areas. These developments, mostly in machine design, included a semi-elliptical, special alloy, cast iron burner which employed a standard fan-type spray nozzle as an orifice. The burner produced a relatively short, flat flame and was designed to operate at a much greater angle than the conventional round burner. Further exploration of some of the principles contained in this new burner led to the development of a flat, rectangular sheet metal burner which was equipped with a replaceable, fan-type, spray nozzle orifice.

Significant improvements of this burner included lower construction costs, improved flame pattern, greater flame output, accurate and fool-proof adjustment and adaptability to different machines. The short, flat flame reduced the danger to leaf damage and the use of smaller orifices permitted earlier flame application. The wider flame pattern provided a longer exposure time that allowed a faster rate of travel. These improvements in design together with the expanding availability of low-cost liquified petroleum gases, the growing shortage of agricultural labor and a desire to fully mechanize farming operations are responsible, in part, for this rising popularity in flame cultivation. The development of the "Stoneville" burner by Jones and the modified "Arkansas" burner by Stanton along with continued research on flame patterns and burners has made available a tool that is more adaptable to general farm use.

STATEMENT OF THE PROBLEM

Basically, the effectiveness of flame cultivation has already been proved. Field tests at several experiment stations in the Cotton Belt have shown that flame cultivation can control a great variety of weeds if the flame is applied at the proper time. The real problem is to develop equipment and application techniques that will give effective weed control in varied crops without reducing yield or quality of the product.

The purpose of this study was to observe presently used application techniques and to evaluate their effectiveness when applied to crops commonly grown in this area. More specifically, the purpose of this study was to determine the following:

1. The effect of various combinations of flame application on the growth and yield of corn plants.
2. The effectiveness of various combinations of flame applications in controlling weed growth in corn production.
3. The effect of rate of ground travel and burner pressure on flame patterns.
4. The economic aspects of flame cultivation--operating costs, total costs and effect of rate of ground travel and burner pressure on the cost of flame cultivation.

This study will help to provide information needed to determine the engineering and economic feasibility of flame cultivation as a practice in Kansas. It will, also, provide basic information necessary for further research on equipment design and improved field application techniques.

REVIEW OF LITERATURE

Because of the relative newness and limited use outside the Cotton Belt, little published information is available concerning flame cultivation of crops other than cotton, especially in the Mid-Central states region. However, research and studies carried on at the High Plains Research Foundation, Halfway, Texas; the Universities of Louisiana, Mississippi, Arkansas, and several commercial equipment manufacturers, show that effective weed control in corn, soybeans, grain sorghum, castor beans and several other crops has been possible without excessive damage to plants or reduction in yield.

In February, 1962, a research project to study "The Use of Flame Cultivation for the Control of Weeds in Indiana Field Crops" was initiated at Purdue University. The stated objectives of this study were:

1. To determine the sensitivity of major weed species common to Indiana field crops to the heat of flaming.
2. To determine the tolerance of corn and soybeans to the application of heat by flaming.
3. To determine the chemical and/or biological changes in the weeds and field crops studies as a result of flaming.

4. To determine the method by which heat is transferred to plant tissue.
5. To make recommendations, if needed, regarding the design of flame cultivation for corn belt conditions.
6. To study the inter-relationships of flame cultivation with other cultural practices.
7. To determine cost input factors which can be used to predict economic feasibility of flame cultivation.

Effect of Various Combinations of Flame Applications on the Growth and Production of Corn Plants

Only limited research data could be found concerning the effects of flame cultivation on corn. Edwards (8) states that the only time that corn yields were reduced in his investigation, was when the weather was dry. But he also cautions that a corn plant is very sensitive to heat during the 6-12 inches height and damage might result from flaming at this stage.

Work at the University of Illinois (16) indicates that flame cultivation may reduce yields in corn. Corn that was flamed after it was 12 inches tall yielded 107 bushels per acre, compared to 119 bushels for corn conventionally cultivated. Corn that was flamed at the 2-3 inches height yielded 73 bushels as compared to non-flamed corn, along side, that made 84 bushels.

Price in his investigations (1960) at the High Plains Research Foundation (21) found that corn flamed four times between the 12-15 inches height and lay-by time showed no significant reduction in yield when compared to non-flamed plots

(130 bushels for flamed and 131 bushels for non-flamed). Both plots were relatively weed free.

Investigations of flame cultivation of grain sorghum by Price (21) gives a more detailed account of the effects on growth and yield of sorghum plants. In one study, flaming was started at the 3-4 inches height and repeated at five day intervals up to a total of five flamings. Three additional regular flamings were made after the sorghum was past the 12 inches height. The results may be seen in Table 2.

Table 2. Effect of flame on sorghum plants (21).

Flame off	Regular flaming	Ave. No. of stalks per foot of row	Yield per acre (lbs./ac.)
0	0	3.20	5234
0	3	3.20	6062
1	3	2.85	4580
2	3	2.47	4580
3	3	2.35	2878
4	3	2.82	3499
5	3	2.62	4389

In other work at the High Plains Research Foundation, a single early flaming at the three inches height to control early weeds, reduced the plant height 4-5 inches during early growth as compared to adjacent unflamed sorghum. This difference in height became less apparent as the crop approached maturity and by the time the sorghum was headed out, there was no difference in height. Yield comparisons were 6148 pounds per acre for unflamed and 5986 pounds for flamed--no significant difference. These plots were treated the same except for the above mentioned treatments.

Matthews and Trupper (1961) made field evaluations of the tolerance of cotton plants to flame cultivation (18). Leaf gradients were measured with temperature-indicating lacquer and thermometer strips on cotton leaves. Minimum lethal temperatures were determined by these methods to be about 170 degrees F. Standard size flame burners set for cross flaming and at conventional gas pressures and field operating speeds gave lethal leaf temperatures from the ground level to a height of 5-6 inches.

This prevented early flaming of young cotton until the development of parallel flaming techniques and the use of midget burners. Parallel burner settings, reduced the height of leaf kill to about 4 inches and in field tests parallel flaming has given the following advantages over cross flaming.

1. It can be applied earlier.
2. Larger weeds can be killed over a wider area of the row.
3. The precision of the burner settings and the smoothness of the row are less critical.

Most studies of flame cultivation in cotton have been made in conjunction with other weed control practices. Therefore, yield reductions from flaming are usually evaluated in comparison with the total weed control programs. Stephenson's studies

(1957 and 1959) show that early cross flaming of cotton caused serious burn damage and was reflected in lower yields.

Effect of Various Combinations of Flame Applications in Controlling Weed Growth

Most plants, including the crops being grown, can be killed with the heat intensities used in flame cultivation. Different kinds of plants are able to withstand differing amounts of heat depending upon their stem structure, age, size and shape. Control of unwanted plants by this method of cultivation is therefore accomplished by moving an intense blast of flame along the base of the weed infested crop. Growth is impeded or terminated in these plants having the least resistance to the high temperatures induced by the flame. When sufficient heat has been introduced to cause dehydration and rupture of cell walls, the plant dies and the process of destruction is completed (29).

Flame cultivation has proved to be an effective tool for controlling most annual and some perennial weeds when properly used (17). Frequent flame application, especially in heavily infested areas, is essential for best results. The use of a flame cultivator in conjunction with conventional sweeps has proved to be a good production practice. By cultivating the row middles and flaming the drill area simultaneously with one tractor unit, man-power requirements are cut in half, machine operating costs are materially reduced, and excessive machine traffic through the field is eliminated.

Several investigators have studied the effect of flaming on various weeds. L. M. Carter, R. F. Colwich and J. R. Traverretti (1959) report that flame cultivation is an effective tool for mid- and late-season control of weeds in cotton after the plants have reached a height of at least four inches. They also state the flame cultivation will control any seedling weed, provided the application is made before the weed develops an extensive root and foliage system (5).

A number of investigations on the use of flame for killing weeds in corn, grain sorghum and several vegetable crops have been made. In general, it was found that weeds were most easily killed when they are small and that large weeds, especially those with considerable foliage, are more economically controlled by two successive flamings at relatively high speeds than by only one at a low speed. Wolfe and Harton (1958) report excellent results at low speeds with a 2000 degree F. flame. Grasses were burned off, colts-foot was charred, and the charred stems of five stemmed weeds were left standing. Sow Thistle was scorched but standing, and, Chickweed was wilted (30).

Cruz (1956) reports control of Foxtail, Heliotrope, Hedgehog Grass, and Caraboo Grass after two burnings. Shallow rooted weeds that are propagated by seed were mostly controlled after the first flaming. Deep rooted weeds which are propagated asexually by runners, root stalks and rhizomes were generally not controlled.

Matthews and Trupper concluded from a three year study (1958-1960) that flame cultivation alone was not very effective in reducing hoe labor in cotton production. Combination of flame cultivation with pre-emergence or post-emergence herbicides were both more effective.

Stephenson found the following comparisons (1957-1958) when a study of the reduction in hoe labor by various mechanized weed control treatments used in cotton production.

Table 3. Reduction in labor by various treatments (18).

Weed control treatment	Hoe labor requirement 1957	Hoe labor requirement 1958
	Man hours per acre	
Conventional Cultivation	20.0	44.3
Pre-Emergence (1)	9.7	42.3
Post-Emergence (2)	12.9	27.5
Pre- + Post-Emergence	9.0	27.0
Pre-Emergence + Flame Cult.	9.6	16.2
Pre- + Post-Emergence + Flame	6.9	7.9

(1) Pre-emergence chemical was 3.4 pound of Karmex DL per acre, broadcast basis, applied on 12-inch band centered on the drill.
(2) Post-emergence chemical was two applications of herbicidal oil, applied on a 10-inch band at the rate of 5-7½ gallons per acre.

It is to be noted that the flame cultivation treatments were especially effective in reducing labor requirements in 1958, and though yields were slightly reduced according to Stephenson as compared to chemical treated only, they compared very favorably with all other treatments.

Effects of Ground Travel and Burner Pressure on the Induced Flame Pattern

Careful adjustment of the burner is a primary requirement for maximum cultivation efficiency. Since the object of flame cultivation is to apply enough heat to kill undesirable weed growth without damaging the crop, it is extremely important that the temperatures involved be known and the effects of such factors as ground travel and burner pressure upon the induced flame (heat) pattern be evaluated.

Much of the early work in this area was concerned with the design and development of improved burners. This led to the development of the flat "Stoneville Burner" by Jones (17). Work with this burner, which is used much today, determined that the optimum position was 45 degrees with the horizontal and perpendicular to the row. The mouth of the burner should be 8-10 inches away from the drill row and 8-10 inches above the row middles. In this position, the flame should strike the ground 2 or 3 inches on the burner side of the drill. This setting gave less flame deflection into the crop from ridges or rough seed beds. Two burners are normally used on each row--one on each side set in tandem so that the flames do not oppose each other. Pressures ranging from 40 to 55 psi were recommended.

Modification of the Stoneville Burner led to the development of the "Arkansas Burner" by Stanton (25). The recommended setting for this burner is similar to the Stoneville Burner except the angle of the flame was 30 degrees from the horizontal.

Laboratory tests and field tests in Louisiana and California show that the distance from the burner tip to the point where the flame touches the row should be eight inches and the flame should strike the row two inches on the burner side of the plants. Recent evaluation with night photography in California have shown that the Stoneville Burner can be lowered to 30 degrees where operated on smooth rounded rows.

Advanced work in Arkansas (28) with flame has resulted in more flexibility with burner settings that may result in wider adaptability of flame to early weed control problems. This involves the use of midget burners and of parallel flaming (positioning the burner parallel with the row and alongside the drill area). This method developed in 1957 for early flaming has gained fairly wide acceptance in the Cotton Belt.

Work by Stephenson (26) indicates that for early flaming of cotton when plants are 4-6 inches, turning the burners parallel to the row has given the best results. By this means the high velocity stream of intense heat is directed onto the weeds on either side of the drill. As the stream strikes the row surface, a fan-shaped pattern of heat distribution results, deflecting a small portion of the stream in the drill area.

After the cotton is eight inches high, the burner can be angled approximately 10-15 degrees toward the drill area to obtain better weed kill in that area. Good results have also been obtained by alternating the use of parallel and cross flaming during the mid and late-season period.

Investigations at Louisiana by Smilie (24), indicate flaming can be effective for weed control in cotton if properly adjusted equipment is used at the right time. Fuel pressure at the burner and the speed of cultivator should be coordinated. For first flaming of young cotton, 30 pounds pressure at three miles per hour is usually satisfactory. For later flamings as the plant matures and becomes more resistant to heat, 50 psi at five miles per hour may be satisfactory. Their work also confirm the recommendations on burner angle settings by other investigations quoted earlier in this section.

Parker, Wooten and Williamson (20) in their evaluation of flame control of conventionally mounted burner and individual mounted burner, found that no particular advantage was gained by mounting the burner individually on separate skids (gauges) for the 30 degree setting, but a more accurate control of the flame was obtained for 45 degree settings from the method of gauging the flame burner individually. This system of individual mounting allows burners to remain at a constant distance above their respective rows.

Their evaluation was made with the use of temperature-indicating lacquer. Field measurements of temperatures were accomplished by painting one side of 12-inch garden stakes with these lacquers. To determine the temperature distribution within the flame, the stakes were then positioned upright on the center of the row, two inches off center and four inches off center. Lacquer which would melt at 175, 200, 225, 250 degrees F.

were used.

The distance from the row and the slope of all burners was set in the shop on a line diagram. The height of all burners in relation to the row was set in the field. The tractor on which the two flame cultivators were mounted was calibrated for a speed of three miles per hour. All burners were equipped with 2-2403 nozzle tips. Burners were operated at 40 psi, throughout the test. Table 4 and Fig. 1 illustrate the values and pattern found from these tests.

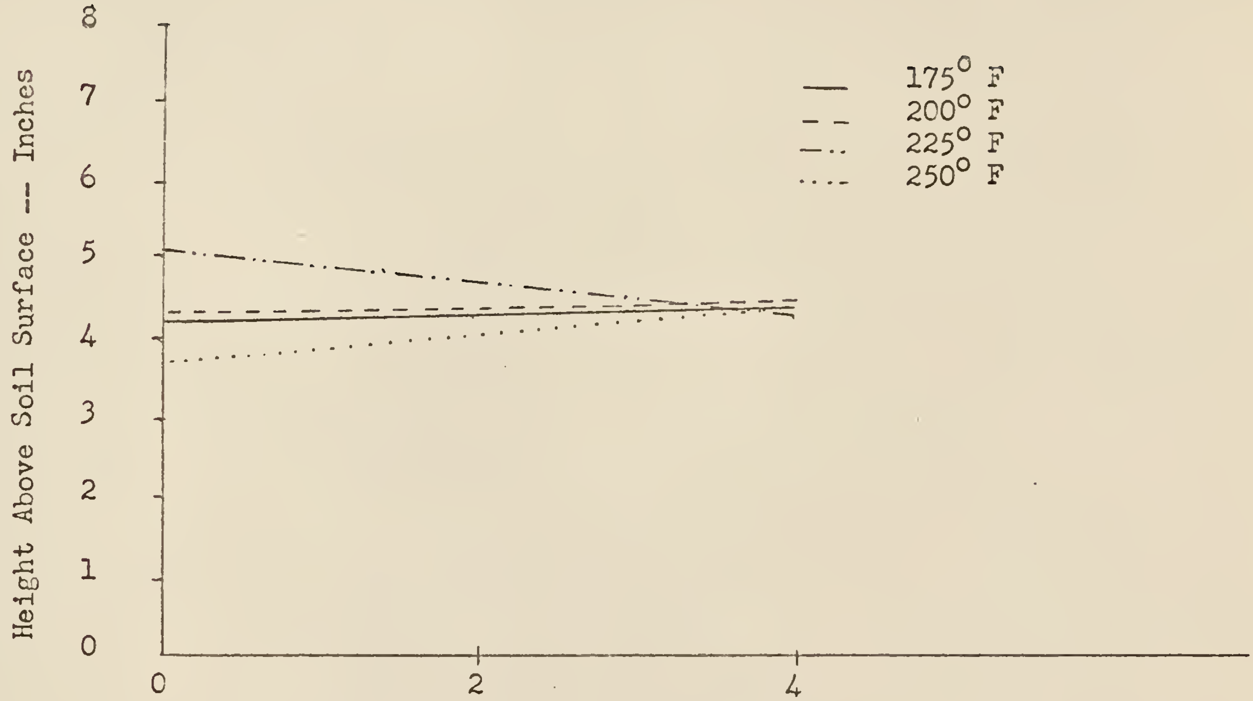
Table 4. Height from soil surface at which designated temperature existed when burners were set at a 30° angle with the horizontal plane, Stoneville, Mississippi, July, 1961.

	Temperature	Distance from center of row: 0	4	Average
	°F.	in.	in.	in.
Conventional Burner Mounting	175	4.3	4.3	4.3
	200	4.4	4.4	4.4
	225	5.1	4.2	4.7
	250	3.8	4.4	4.1

EXPLANATION OF PLATE I

Fig. 1. Diagram showing the patterns of the temperatures that existed for a conventional burner operated at 40 PSI burner pressure and a ground Travel of 3 MPH. Burner angle was 30 degrees with the horizontal.

PLATE I



Horizontal Distance from Center of Row -- Inches

Fig. 1

Economic Aspects of Flame Cultivation

Cruz (1956) estimates that about one-fourth of all the work done by the American farmer is expended on the control of weeds (8). Figures for Kansas indicate that weed losses may be as high as $500,000 per year. Most row crops in Kansas will require 2-4 cultivations for good weed control. With conventional cultivation costs varying from $0.80 - $1.00 per acre per cultivation, depending upon size of operation and labor costs, annual weed control costs could vary from $1.60 - $4.00 per acre.

Chemical weed control may afford complete control of weeds in the row under ideal conditions, but results are very dependent upon proper application, timeliness and optimum weather conditions. The following table is compiled from research data obtained from the Department of Agronomy, Kansas State University and compares the cost of material for various recommended application rates on commonly grown crops.

Edmondson and White (1952) estimate the total cost of flame cultivation to average $1.44 and $0.97 per machine acre for 2-row and 4-row cultivators respectively (7). Their figures were derived from data obtained from twenty-six farmers in the Arkansas Delta area. Although these costs pertain to cotton production, they may be roughly applied to other crops in that area.

In order to have season-long weed control in cotton production, it is necessary to use flame cultivation in combination with other methods. Therefore, the above stated figures are not intended to reflect total weed control costs, but merely costs

Table 5. Material costs for chemical weed control.

Crop	Material	(1)Rate lb./ac.	Cost per pound (2) Dollars	Material cost per acre
Corn	Atrazine	2-3	$2.89-3.13(80%)	$ 5.78- 9.39
	TBC	4-6	$3.40	$13.60-20.40
	2,4-D	1½-2	$1.00	$ 1.50- 2.00
Soybeans	NPA	4	$2.25-2.90	$ 9.00-11.60
	Amiben	3-4	$5.00	$15.00-20.00
	CDAA	4-6	$2.00	$ 8.00-12.00
Grain Sorghum	(3)Propozine	2	$2.89-3.13(80%)	$ 5.78- 6.20
	(4)2,4-D	1/4-1/3	$1.00	$ .25- .33

(1) Chemical Weed Control in Crops, Agricultural Experiment Station Bulletin 444, 1962, Kansas State University.
(2) Prices as of Spring, 1962.
(3) Approved only for use on sorghum harvested for seed.
(4) Post-emergence recommended only.

for flame cultivating applications. In other words, if three applications were made with a four-row "flamer" the total flaming costs would be $2.91 per acre (3 x $0.97/ machine acre).

The farmers interviewed by Edmondson and White flamed an average of sixty-eight acres with 2-row equipment and 147 acres with the 4-row flamer. All of the acreage handled by the 2-row machine was flamed twice and 47.6 acres covered a third time or a total of 183.6 machine acres (2 x 68.0 = 136 + 47.6 = 183.6). The 4-row machines handled about 381 machine acres each (147 acres twice and 60 per cent of which was covered a third time.)

The derived total cost was divided into two groups: Overhead costs (depreciation, interest on investment, taxes, insurance, shelter, etc.) and operating costs (maintenance, repairs, fuel for flaming device, labor and tractor costs). Of the overhead costs, depreciation and interest on investment are the only two taken into account as taxes on equipment could not be separated from the total tax assessment. None of the farmers report any insurance and shelter was available without extra cost.

The estimated total annual overhead cost depends on the amount charged annually for depreciation and interest. The annual depreciation charge made per machine was determined by initial purchase price and the estimated length and life for the equipment.

The purchase price (1952) of a new 2-row flaming machine was approximately $324 (4-row machine--$508) and such a machine had an estimated life of six years (4-row machine--seven years). Thus, the annual depreciation per machine was about $54 for the 2-row machine and $73 for the 4-row cultivator. Since, these machines covered 183.6 and 381.2 acres per machine respectively, the depreciation charges per machine acre were thirty cents for the 2-row and nineteen cents for the 4-row machine.

An annual interest rate of 6 per cent was used to derive annual interest on investment costs. These amounted to $9.73 for the 2-row and $15.24 for the 4-row cultivators or five cents and four cents per machine acre respectively. Total overhead costs amounted to thirty-five cents and twenty-three cents per machine acre for the two sizes of machines. It should be noted that these are average overhead costs for the group of farms studied, and relate only to the indicated levels of average operation.

Repair and maintenance were consolidated in this summary and amounted to $15.71 and $8.03 per 2-row and 4-row machines. This reflects a $0.09 and $0.02 cost per machine acre. Tractor costs were estimated at ninety cents per hour exclusive of labor. Tractor time per machine acre was calculated at twenty-six cents and seven cents per hour for the two sizes of flamers, which amounted to a cost of twenty-three cents and six cents per machine acre respectively.

EQUIPMENT AND PROCEDURE

Although considerable previous study and research has been devoted to "flaming" in other states, this method of weed control is virtually new to Kansas and only limited information is available that may be directly applicable to the ecologic, agronomic and climatic conditions to be found here. Therefore, it was deemed sufficiently important to devote considerable effort to determine the effectiveness of presently recommended practices and techniques when applied to these conditions. This was not merely for the sake of academic validity but to provide a sounder basis for making recommendations to the increasing number of Kansas farmers using flame cultivation in their weed control programs.

Equipment

A commercial 2-row flame cultivator was obtained from the Gotcher Engineering and Manufacturing Company, Clarksdale, Mississippi. This cultivator was used in all tests conducted in these studies. A picture of this machine may be seen in Fig. 2. The components of a flame cultivator consist of a high pressure tank (LP-gas), tank fittings, fuel lines, pressure gauge, shut-off valves, rockshaft, attaching frame, skid assembly, burner supports and burners. A schematic diagram of these components is shown in Fig. 3.

A vapor valve is used at the top of the fuel tank to supply gas to the burners. For the larger four- and six-row machines, the normal practice is to withdraw liquid from the bottom of the tank and vaporize fuel before it reaches the burners. In this practice, water is circulated from the cooling jacket of the tractor engine around a coiled section of the fuel feeder line and returned to the tractor radiator. If the tractor is not equipped with a water pump, an auxiliary pump may be installed and driven from the tractor fan or power-take-off.

After gas is drawn from the tank, it passes through a pressure regulator whereby the operating pressure of the burners may be controlled. It then goes to a manifold where it is channeled to the individual burner by means of a flexible hose (or copper tubing). A quick-opening valve, installed in the line just beyond the regulator and within easy access of the tractor operator, allows the burner to be turned on and off. This valve has a small hole drilled in the gate (or a by-pass) to allow a pilot light to burn while the burners are turned off for turning at the ends or whenever it is necessary to stop the machine in

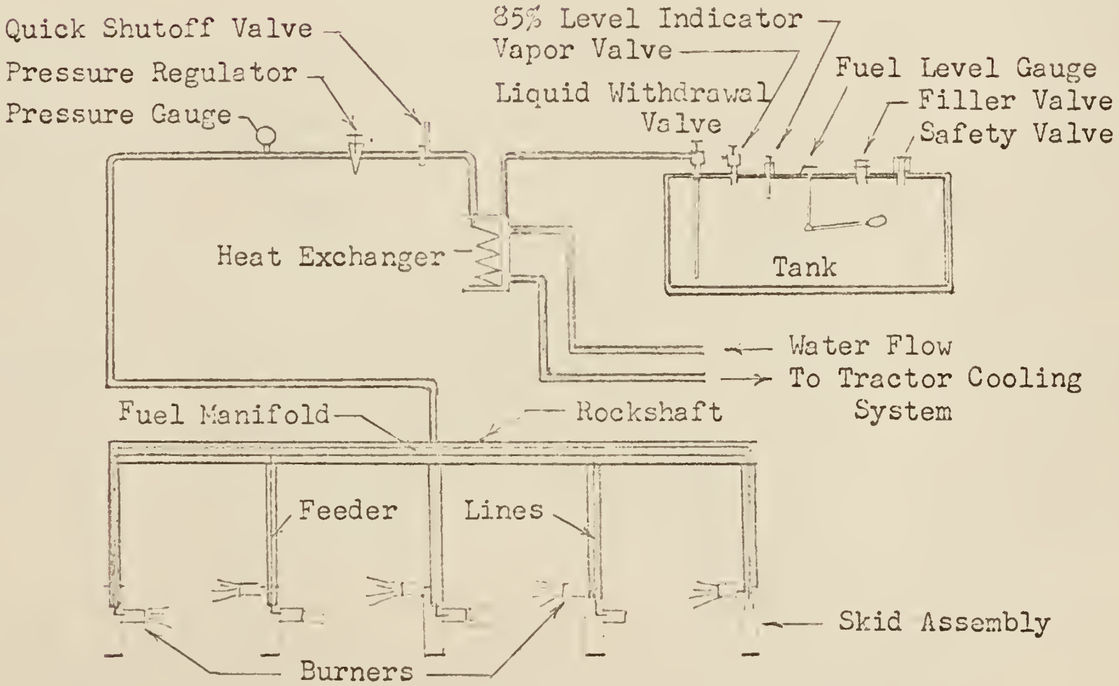
EXPLANATION OF PLATE II

Fig. 2. Two-row flame cultivator mounted on a Ford tractor with a three-point hitch. This was the equipment used in all tests in this study.

Fig. 3. Schematic diagram showing the component parts of a typical flame cultivator.

PLATE II

Fig. 2



Schematic Diagram of a Flame Cultivator

Fig. 3

the field.

The fuel tank, all fittings and hoses meet state specifications for use with LP-gas. A safety valve, to relieve exceedingly high pressures, is provided as standard equipment on this machine. The fuel tank has a 100 gallon capacity and is equipped with an 85 per cent level indicator and fuel level gauge.

The burner support brackets allow complete adjustment of burners--both in elevation, azimuth, and distance from the row. Adjustment for varying row widths can be made with the skid assembly. The skids act as gauging devices to align the burners on the row and maintain a relative elevation in regard to the seed bed. A close-up of this arrangement may be seen in Figs. 4, 5, and 6.

A Ford tractor equipped with a three-point pick-up attachment was used with the cultivator. The tractor was also equipped with a two-way hydraulic cylinder which afforded a convenient way of leveling and regulating the burners independently of the pick-up attachment. This was especially convenient for turning, backing and maneuvering in the small plots.

The tractor was equipped with a tachometer which allowed an easy way of calibrating and regulating the rate of ground travel, which was necessary in the studies made. This calibration was accomplished by measuring off a distance of 100 feet and calculating the time required to travel this distance for the desired rates of ground travel.

Table 6 shows the time required to travel the 100 feet for

EXPLANATION OF PLATE III

Fig. 4. Burner support brackets showing how adjustments in the burner setting may be made.

Fig. 5. Angle of burners are controlled by the adjustment shown here.

PLATE III

Fig. 4

Fig. 5

EXPLANATION OF PLATE IV

Fig. 6. Adjustment of burners for various row widths is made by positioning the skids.

PLATE IV

Fig. 6

Table 6. Time Required to Travel 100 Feet.

Rate of travel		Time of travel 100 feet
MPH	Feet/Sec.	Seconds
1.0	1.467	68
1.5	2.200	45
2.0	2.934	34
2.25	3.300	30
3.0	3.501	28

several rates of travel used in this study. Several throttle settings were tried for each rate of travel until the time required to traverse the 100 feet were the same as that calculated above. The corresponding tachometer reading was noted which allowed the correct engine rpm to be selected for the rate of ground travel desired. Again, this pre-setting of the throttle was essential with the small plots used in these tests.

The flame pattern study involved modifying the cultivator to off-set one or more of the burners from the tractor. This allowed more room and ease to adjust the burner and to measure and record the flame temperature patterns. Figure 7 shows the modified arrangement. A commercially available temperature sensitive material (Thermostik) was used to measure and indicate the temperatures involved. Some difficulty was encountered in finding a material on which to apply these temperature sensitive indicators. A material was needed that would not ignite, discolor or char under the induced temperatures and yet one that had a specific heat or heat resistance similar to plant foliage.

Several materials were tried including asbestos paper, wood, fire brick and various metals. A fine mesh screen wire was finally selected as the best. The temperature sensitive material, which was in the form of a marking pencil, when applied to the screen wire would embed in the mesh and respond to the flame temperatures almost independent of the reaction of the metal wire. The open surface of the screen also caused very little distortion of the flame. Pictures of this equipment and the marking pencils are shown in Figs. 7, 8, 9, and 10.

The fuel consumption tests involved weighing the fuel consumed. This was accomplished by the use of two platform scales. The cultivator and fuel were weighed before and after each test and the fuel consumed was determined from these weights. Some difficulty was encountered in obtaining similar results in replicated tests. Upon further investigation it was discovered that water, apparently from the heavy spring rains, had gotten into the hollow frame construction of the cultivator. As the successive consumption tests were run, some of the water was evaporated by the heat and was, of course, measured as fuel consumed. Holes were drilled into the frame and the moisture drained out. This corrected the problem.

Method of Procedure

Any attempt to evaluate the effectiveness of flame cultivation requires some method of measurement. Although several

EXPLANATION OF PLATE V

Fig. 7. Rear view of two-row flame cultivator showing how the machine was modified (off-set to the right) to facilitate making the flame pattern studies.

Fig. 8. The temperature sensitive marking pencils and the wire panel used in conducting the study on flame patterns.

PLATE V

Fig. 7

Fig. 8

EXPLANATION OF PLATE VI

Fig. 9. Screen-wire panel in position as it was used in the study of flame patterns. The one-half inch strips of temperature-sensitive material applied to measure the induced temperatures may be seen on the panel.

Fig. 10. A view of the nine panels used in conducting the study on flame patterns. These panels are positioned at various distances from the line of burner travel.

PLATE VI

Fig. 9

Fig. 10

approaches to such a study might be made, four separate items were to be measured in this project--(1) effect of flame (temperatures) on the crop plant, (2) effectiveness in reducing weeds, (3) effect of two controllable variables on the flame pattern, and (4) economic feasibility of flame cultivation.

Corn was the crop selected to be studied and sixty-three plots were planted and used in these investigations. All plot work was correlated and carried on cooperatively with Dr. Laurel Anderson, Department of Agronomy, Kansas State University. Dr. Anderson is presently carrying on similar studies of weed control with the use of chemical weed killers. Although it was not within the scope of this project to compare the results of these two methods, it was felt desirable to correlate them so that evaluations and comparisons might be made by others if desired.

The plots were located on the Kansas State University Agronomy Farm, north of the campus. They were intentionally located on a site known to be weedy to assure that weeds would be present. Four-row plots, twenty-seven feet long were used (.00824 acre) and sixteen-foot alley ways were provided for turning equipment.

A commercial variety, Dekalb 3x1, was planted May 1 and 2 at the rate of 20,000 seeds per acre (approximately). The average stand count was near 19,000 plants per acre. Corn was planted in 40-inch rows. No fertilizer was added but the area is known to have a high fertility level and further application was not considered desirable.

Effect of Various Flame Applications on the Growth and Yield of Corn. The primary objective of this test was to measure the effect of various flame applications upon the yield of corn. Plant heights were measured at several periods throughout the growing season to determine the effects upon growth. In order to measure and determine these effects, it was necessary to standardize or hold constant all controllable factors except those being measured, namely, the date and number of flame applications. The following factors were standardized for all plots and treatments.

1. Variety
2. Planting Date
3. Planting Rate
4. Row Spacing
5. Fertility (applied).

To reduce the effects of unknown or uncontrollable factors such as (1) soil type, (2) residual fertility, (3) insects or disease, (4) wind, and (5) others, each treatment was replicated three times and the plots were located randomly throughout the test site.

This test actually involved part of two separate experiments--(1) The Effect of Flame Cultivation on Yield When the Weed Factor is Eliminated and (2) The Effect of Flame Cultivation on Yield under Normal Field Conditions. Four different flame application dates were used and these were identified by the stage of crop growth.

1. Pre-emergence (before or as the corn emerges)
2. 2-4 inches high
3. 8-10 inches high
4. 14-16 inches high.

These stages were selected on the basis of previous work by other researchers and because it afforded a fairly uniform variance in growth between applications. No information was available concerning pre-emergence flaming although it was known to have been used on other crops. Earlier work by Edwards (8) indicated that flaming when 6 to 12 inches high is critical for corn and that after the 12-inch height it is generally tolerant to normal flaming practices.

The Effect of Flame Cultivation on Yield When the Weed Factor is Eliminated. In this experiment the entire area was treated with Atrazine (pre-emergence herbicide) at the rate of ten pounds per acre. Its purpose was to eliminate weeds so that any difference in yield of the variously treated plots would be a function of these flame treatments. Seven different flame treatments and a check (no-flame) were used. These treatments and their corresponding plot numbers are shown in Table 7. Figure 11 shows the actual plot arrangement and location.

This test was designed to show if there were any differences in yield due to either the time of flaming or the number of flame applications. Likewise, a general observation of the effects on plant height was made for the several flame treatments compared.

Table 7. Treatments and corresponding plot numbers for experiment on Effect of Flame Applications on Corn Plant.

Treatment	Number of flamings	Plot numbers		
1. 2-4"	1	2	8	16
2. 2-4" + 8-10"	2	6	12	18
3. 2-4" + 8-10" + 14-16"	3	1	10	15
4. 8-10"	1	5	9	20
5. 8-10" + 14-16"	2	4	14	19
6. 2-4" + 14-16"	2	7	13	21
7. 14-16"	1	3	11	17

The Effect of Flame Cultivation on Yield under Normal Field Conditions. The plots used in this experiment were also the same as those used to conduct a weed count for evaluating the ability of these various flame treatments to control weeds. This was done without any effect upon the above stated experiment and will be outlined in more detail in the following section. It was deemed important to determine how flame cultivation, under normal field conditions, might affect yield. The experiment employed eleven flame treatments together with a "normal cultivation" and a "no-flame - no cultivation" treatment. Table 8 and Fig. 12 show the treatments and corresponding plot arrangement.

The results of these treatments should reflect both the beneficial effect, if any, of weed control and the effect of flame treatments upon the corn plant. This test was not designed

Table 8. Treatments and corresponding plot numbers for experiment on Effect of Flame under Normal Field Conditions.

Treatment	Number of flamings	Plot numbers		
1. Pre-emergence	1	5	15	27
2. Pre + 2-4"	2	8	22	31
3. Pre + 2-4" + 8-10"	3	12	20	34
4. Pre + 2-4" + 8-10" + 14-16"	4	2	14	30
5. Pre + 8-10"	2	6	18	37
6. 2-4"	1	10	23	39
7. 2-4" + 8-10"	2	4	26	35
8. 2-4" + 8-10" + 14-16"	3	1	25	28
9. 2-4" + 14-16"	2	9	19	33
10. 8-10" + 14-16"	2	13	16	38
11. 8-10"	1	11	21	36
12. No Flame - No Cult.	-	7	24	32
13. Normal Cultivation	-	3	17	29

to be compared with the previous experiment on yields. Rather, it was intended to measure and determine how yields might be affected under normal field conditions. The two middle rows of each plot were harvested except in a few instances where uneven stands made the selection of other rows more representative. Plots were harvested by hand on October 5th.

EXPLANATION OF PLATE VII

Fig. 11. Plot layout for the experiment to determine--Effect of Flame Cultivation on Yield When the Weed Factor is Eliminated. Layout shows plot number and corresponding treatment.

Fig. 12. Plot layout for the experiment to determine--Effect of Flame Cultivation on Yield Under Normal Field Conditions. Layout shows plot number and the corresponding treatment.

PLATE VII

21 Treat. No. 6	14 Treat. No. 5	7 Treat. No. 6
20 Treat. No. 4	13 Treat. No. 6	6 Treat. No. 2
19 Treat. No. 5	12 Treat. No. 2	5 Treat. No. 4
18 Treat. No. 2	11 Treat. No. 7	4 Treat. No. 5
17 Treat. No. 7	10 Treat. No. 3	3 Treat. No. 7
16 Treat. No. 1	9 Treat. No. 4	2 Treat. No. 1
15 Treat. No. 3	8 Treat. No. 1	1 Treat. No. 3

Fig. 11

	27 Treat. No. 1	14 Treat. No. 4
39 Treat. No. 6	26 Treat. No. 7	13 Treat. No. 10
38 Treat. No. 10	25 Treat. No. 8	12 Treat. No. 3
37 Treat. No. 5	24 Treat. No. 12	11 Treat. No. 11
36 Treat. No. 11	23 Treat. No. 6	10 Treat. No. 6
35 Treat. No. 7	22 Treat. No. 2	9 Treat. No. 9
34 Treat. No. 4	21 Treat. No. 11	8 Treat. No. 2
33 Treat. No. 9	20 Treat. No. 3	7 Treat. No. 12
32 Treat. No. 12	19 Treat. No. 9	6 Treat. No. 5
31 Treat. No. 2	18 Treat. No. 5	5 Treat. No. 1
30 Treat. No. 4	17 Treat. No. 13	4 Treat. No. 7
29 Treat. No. 13	16 Treat. No. 10	3 Treat. No. 13
28 Treat. No. 8	15 Treat. No. 1	2 Treat. No. 4
		1 Treat. No. 8

Fig. 12

Effect of Various Flame Treatments on Control of Weed Growth. The object of this test was to determine the difference in weed control resulting from various flame application dates and to evaluate the effectiveness of various combinations of these flame applications in terms of reduction in weeds. The same application dates (pre-emergence, 2-4 inches, 8-10 inches and 14-16 inches) were used. In fact, as stated before, the same set of plots were used as in the experiment on yield under normal field conditions.

In order to develop an effective technique of controlling weeds with flame, it was necessary to determine the best stage and number of applications needed for various levels of weed control. Although the entire area of the plots could have been flamed, only a sixteen-inch band over the row was treated (eight inches on each side of row) and evaluated. An actual weed count of two rows in each plot was made between July 17-24. At this stage the corn had almost reached its full height and there was maximum shading of the rows. Although additional weeds may have appeared later in the growing season, it is doubtful if they would be of an economic importance.

For purposes of making the weed population count, the sixteen-inch control band was identified by placing four stakes down each row--two on each side, eight inches from the center of the row and fifteen feet apart. By wrapping a cord around the stakes the area could be identified and the number of weeds within this area determined. A diagram of this arrangement may be seen in Fig. 13. Weeds outside this area were controlled by the use of cultivator sweeps down the middles. The two rows selected in each plot for making the weed population count were determined by the use of a random table of numbers and were not necessarily the same as were harvested in the study on yields. The actual rows in each plot used in this weed count are shown in Table 14.

The time and number of flame applications are only two of several variables which have pronounced influence upon the measured results. Burner setting, rate of ground travel, burner pressure, type of burner and the shape of seed bed are factors over which the operator has some control. Wind, temperature, soil moisture, humidity, precipitation and other climatic conditions are a few of the factors over which he has very little control. To avoid the need of evaluating these above stated variables it was desirable to hold them constant for all treatments, so far as possible. The problem was to select values or constants which were known to be effective and which are being used by other research workers. It was not possible to control the climatic or soil conditions but it was possible to measure and record some of these factors and to use them in evaluating the recorded data. These are discussed in the section on results of study.

Burner setting is one of the variables which offer several selections that have proven to be effective. California recommendations (6) were used in this study. These are the same as

EXPLANATION OF PLATE VIII

Fig. 13. Diagram of the sixteen-inch control band down the row. The stakes and cord show how the area was identified for the purpose of making the weed population count. Area included eight inches on each side of the row and fifteen feet long in each row (twenty square feet).

PLATE VIII

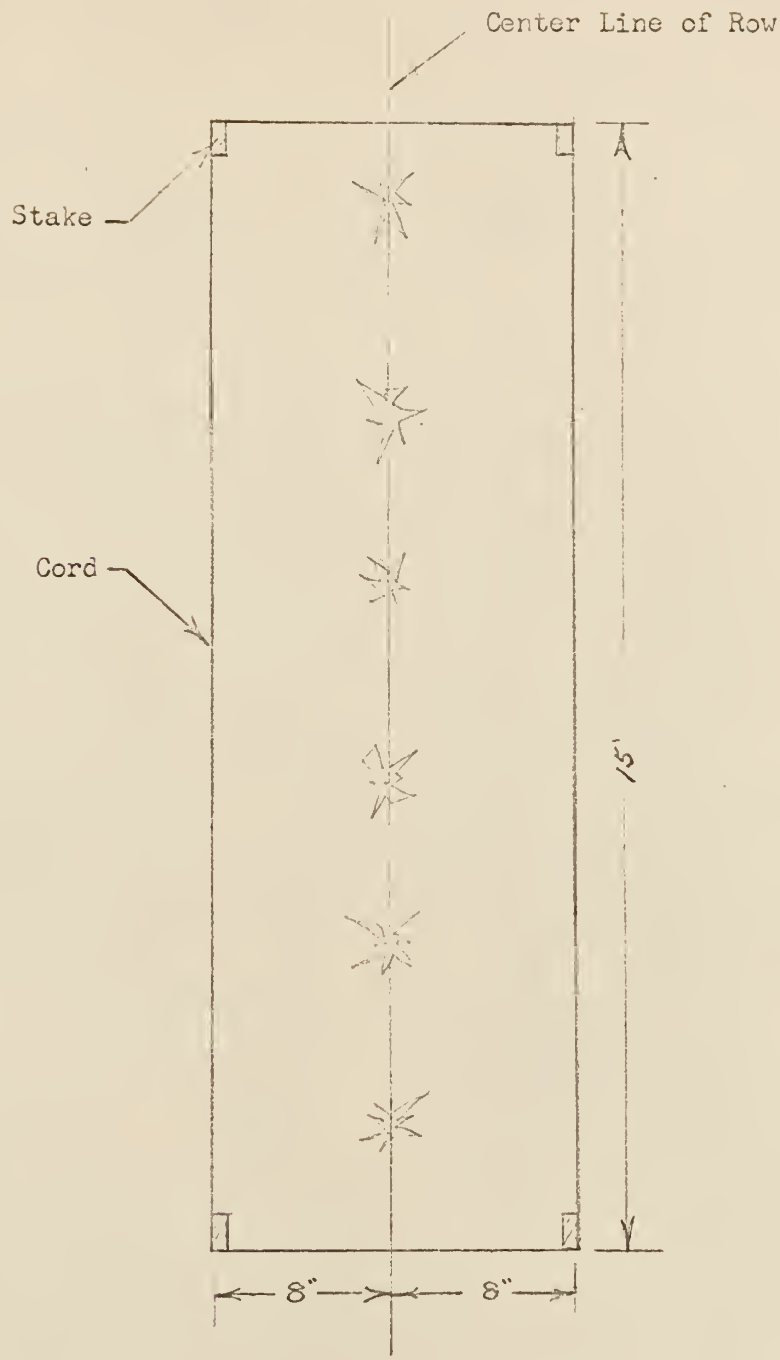


Fig. 13

Mid-South recommendations except the elevation angle may be raised to forty-five degrees for the purpose of minimizing flame deflection on rough seed beds. A diagram of this burner setting is shown in Fig. 14. It consists of orienting the burner perpendicular to the row with the mouth of the burner four inches above the row middle and approximately nine inches away from the row. The burner is declined thirty degrees with the horizontal and the center of the flame should strike the ground surface about two inches away from the plant on the burner side of the row.

This method consists of using two burners--one on each side of the row. The burners are off-set or staggered so that the flame patterns do not oppose each other, but afford a complete cover on each side of the row and offer a longer exposure time to the weed infested area. Figure 15 shows how this arrangement is accomplished.

Although a faster rate of travel could have been used in this study, three miles per hour was the rate selected. Again, this met recommendations used in California and in several of the southern states, as applied to cotton production.

Burner pressure is another variable which offers several selections. A middle of the range selection--forty pounds per square inch--was used. This value is being used in several other states and was felt it would be effective in Kansas. The machine was equipped with "Stoneville" burners and utilized 2-2502 spray nozzles. A close-up of the burner is shown in Figs. 16 and 17.

EXPLANATION OF PLATE IX

Fig. 14. Diagram of the burner showing the angle and position relative to the row used in this study. A setting recommended by California researchers (4) and is, also, used throughout the cotton belt.

Fig. 15. Diagram showing how the two burners are positioned so that the flame patterns do not oppose each other but provide a longer exposure time to the weed infested area. Diagram also shows the distance of the burner from the row.

PLATE IX

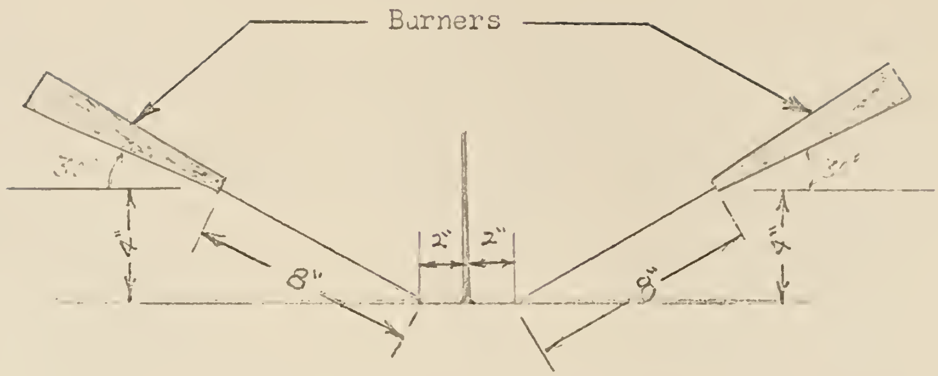


Fig. 14

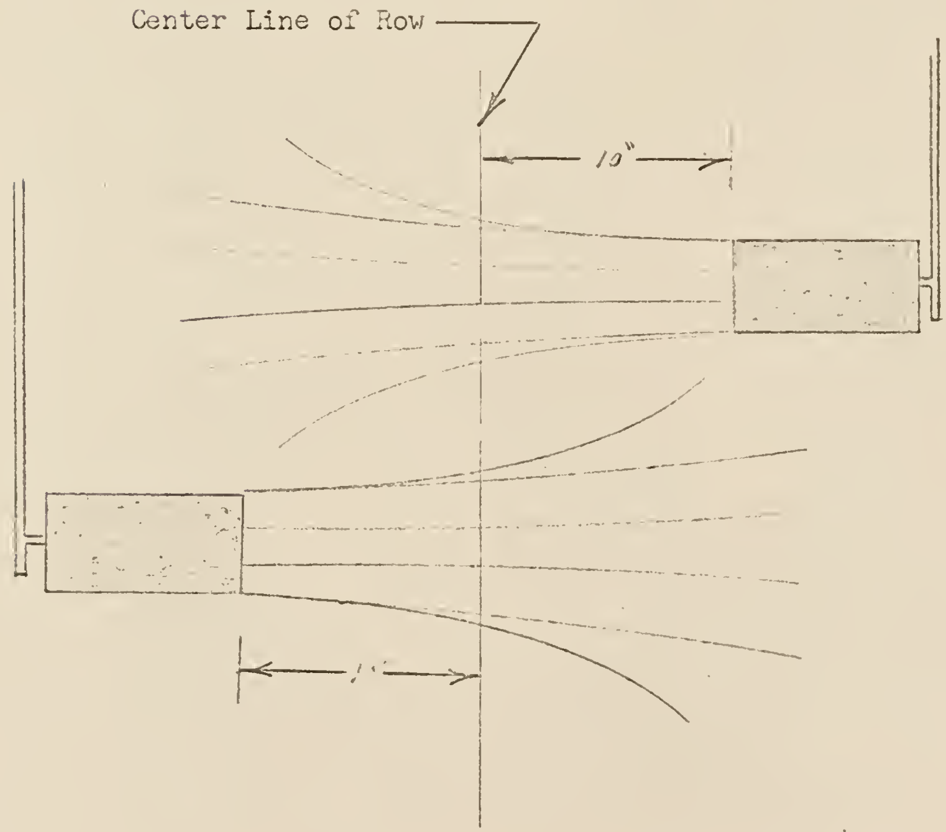


Fig. 15

EXPLANATION OF PLATE X

Fig. 16. Close-up of the "Stoneville" burner as was used in study on flame cultivation.

Fig. 17. Close-up view of burner and the panels used in making the flame pattern investigation.

PLATE X

Fig. 16

Fig. 17.

The corn was surface planted with a one-row plot planter and a fairly level seed bed was maintained.

Effect of Rate of Ground Travel and Burner Pressure on Applied Flame Patterns. The most commonly used field method of adjusting and setting the burners is by visual observation of the flame. Because the flame produced is practically invisible in daylight, adjustments are usually made just before or after darkness when the flame pattern is easily visible to the operator. Although this method is generally felt to be reliable so far as visual pattern is concerned, it provides no way of actually determining the temperatures within the pattern nor does it provide any way of determining the effect of ground travel (exposure time) upon these temperatures and thermal patterns.

The object of this study was to identify and measure the temperature levels and thermal patterns within the applied flame and to determine what affect variations in rate of ground travel and burner pressure have upon these measured values. In order to be able to measure the temperatures within the flame as it passed over an identified section of the row or control area, it was necessary to devise a technique that would measure and record the maximum temperatures. Such a record of temperatures from identified positions across the row would afford a positive way of measuring and calibrating the effect of such variables on the induced thermal pattern.

The devised method consisted of using temperature sensitive marking pencils (Markel Company, Chicago, Illinois) that melt when exposed to pre-determined temperature levels. Figure 8 shows the marking pencils used. The temperature sensitive indicators were positioned in and along the row at pre-determined sites to record the temperatures as the applied flame passed by.

The temperature sensitive material was applied to panels of common screen wire (two thicknesses). These panels were twenty-four inches long and seven inches wide and were suspended from a framework of two metal stakes with removable cross-rods which were strung through the panels similar to a panel curtain. A picture of this arrangement may be seen in Fig. 18.

The temperature sensitive material was applied in approximately one-half inch width strips. Each panel had indicators for the following temperature levels--200, 300, 400, 500, 600, and 700 degrees Fahrenheit. As the flame passed each panel, the respective materials would melt according to the temperatures induced and the areas exposed. Thus, it was possible to not only measure the temperatures and thermal areas involved, but also to identify this temperature pattern in relation to ground level, crop row or other relative points.

This information together with similar information from several points in and alongside the row made it possible to construct an isothermal pattern of the flame as would be viewed down the row. Figures 19 and 20 show how these points were located and the way these panels looked in conducting the tests. The measured pattern is the same as would be viewed by the operator in making a visual adjustment of the burners, except it is

EXPLANATION OF PLATE XI

Fig. 18. Picture of the wire panel with the temperature sensitive material applied. The various temperature levels used were--200, 300, 400, 500, 600, and 700 degrees Fahrenheit.

PLATE XI

Fig. 18

EXPLANATION OF PLATE XII

Fig. 19. A view looking down the row showing the location of the various wire panels in relation to the burner position.

Fig. 20. A close-up view of the burner as seen by the operator in attempting to make a visual adjustment of the flame pattern.

PLATE XII

Fig. 19

Fig. 20.

also evaluating the exposure time for the selected rate of ground travel.

With this technique of measuring and recording temperature levels and thermal areas it was then possible to observe and measure the effects of such variables as ground speed and burner pressure on these induced values. It was also possible to calibrate the rate of heat application for any selected value of these variables and to determine if there was any correlation between the rate of energy applied (BTU per foot of row) and the measured thermal patterns, also, to determine if equal energy levels produced similar thermal patterns regardless of the values of these variables. Three separate experiments were conducted.

1. Effect of Rate of Ground Travel on Induced Flame Pattern.
2. Effect of Burner Pressure on Induced Flame Pattern.
3. Energy Application Rate (BTU per foot of row) as Guide for Applying Flame.

The burner settings for all tests were the same as described before--perpendicular to the row, declined thirty degrees from horizontal and mouth of burner approximately four inches above the soil surface. Only one burner was used in conducting these tests.

In the first experiment three ground speeds were used--one, two and three miles per hour. The burner pressure was constant for all tests at forty pounds per square inch. The second experiment utilized a constant ground speed of three miles per hour but varied the burner pressure for thirty, forty and fifty pounds per square inch. The third experiment involved selecting three sets of values for ground speed and burner pressure which produced similar heat application rates. The following values were used.

1.5 miles per hour - 30 pounds pressure = 153 BTU's/foot of Row

2.0 miles per hour - 40 pounds pressure = 157 BTU's/foot of Row

2.25 miles per hour - 50 pounds pressure = 156 BTU's/foot of Row

Economic Aspect of Flame Cultivation. The purpose of this phase of the study was to determine the economic feasibility of flame cultivation as a weed control practice in corn production under conditions to be found in Kansas. Two primary areas were investigated--operational and total costs on a per hour and per acre basis and also what effect the rate of ground travel and burner pressure had on the cost of flame applications.

Operational Costs. These costs include maintenance, repairs, fuel for the flaming device, labor and tractor costs. Because of the newness of flame cultivation in this area, no survey of actual field operations was possible. Costs were determined by calculating the values for the above mentioned items from the best known and approved techniques. These figures were developed for both two-, four-, and six-row cultivators.

Maintenance and repair costs were obtained from values derived by Edmondson and White (7) in their survey of flame cultivation operations in Mississippi. Fuel costs for the actual flame application were computed from fuel consumption tests conducted to determine the fuel usage level under various burner pressures.

Fuel Consumption Test (two-row machine). This test was to determine the hourly fuel consumption and the fuel costs per acre for a two-row flame cultivator operating at thirty, forty, and fifty pounds per square inch pressure. These figures were then used to calculate similar costs for four- and six-row machines. The test consisted of weighing the fuel consumed for fifteen-minute intervals operating at the above stated burner pressures. Because of the size of the tank and the manner in which it was attached, it was determined to be easier to weigh the entire machine before and after each test. The tests were repeated twice and the values averaged and converted to gallons per hour.

Labor costs are based on the hourly minimum wage scale of $1.25 per hour. Tractor costs were computed from information and research data from Kansas State University (17), University of Nebraska (9), and the University of Georgia (10).

Investment and Total Costs. Total costs reflect operational costs plus fixed or ownership costs. These include depreciation, interest on investment, taxes, insurance and shelter. Fixed costs, unlike operational costs, are independent of the use of the machine. However, when this cost is expressed on an acre or machine-acre basis, the amount of use greatly affects this value.

Values for these investment costs are based on local conditions and average machine use. They do not reflect optimum or ideal conditions but those commonly found in this area. Again, total costs were computed for both two-, four- and six-row cultivators.

Effect of Burner Pressure and Rate of Ground Travel on Cost of Operation. As was explained in the study on flame patterns, burner pressure and rate of ground travel may be selected in various combinations to obtain either (1) the same heat application rate (BTU per foot of row) or (2) any desired heat application rate needed to do a certain job. The purpose of this phase of the study was to determine the economic significance of these two variables as they apply to cost of operation and the cost of BTU's per foot of row.

These computed values were based on the previously described fuel consumption tests and several selected rates of ground travel. These costs are also computed for the two-, four- and six-row machines.

RESULTS

Generally, the results of this study correspond with the findings of other research on flame cultivation. In areas where these results do differ or in areas where no comparable studies have been made or results published, it should be noted that the following findings are based on only one year's study and definite conclusions may be hazardous until further research can be done.

No attempt was made to control such production factors as precipitation, length of growing season, temperature or amount of sunlight in these tests. However, because growing seasons do vary from year to year, the data shown in Table 9 provides information pertinent to the conditions under which these data were obtained. Any analysis of these findings should be made in light of these conditions.

In general, the growing conditions were not abnormal for the year. It is, however, worth noting that although total rainfall during May was above normal the month was actually exceptionally hot and dry (see temperature data). The bulk of precipitation for the month (4.7 inches) occurred in one rain on the 28th day of May and was preceded by nine weeks with only one shower of one-half inch or greater rainfall.

No record of soil temperature or soil moisture was made. Table 10 does provide a record of a few of the observed conditions that existed at the time of each flame application. These conditions do not reflect optimum or even desired conditions for crop production or flame application but are merely a record of the conditions as they existed for this year's study and may be helpful in comparing these results to future findings.

Table 9. Climatological data.

Month	Average temperature °F		Precipitation (inches)		Evaporation (inches)	
	Normal	1962	Normal	1962	Normal	1962
April	52.3	51.0	2.63	1.14	6.40	6.01
May	63.5	72.2	3.75	5.98	7.45	10.00
June	74.1	71.9	5.00	4.40	8.94	7.72
July	79.4	75.9	3.64	2.86	10.42	8.33
August	78.8	76.9	3.03	4.50	9.11	9.51
September	68.6	64.5	4.09	4.56	7.47	4.61
Total or average	69.4	68.7	22.14	23.44	49.79	46.18

Table 10. Observed conditions at flamings.

	Pre-emergence	2-4 inches	8-10 inches	14-16 inches
Date	May 7	May 10	May 23	June 11
Time of Day	10-11 AM	9-10 AM	10-12 AM	9-11 AM
Wind	S - 10-15	SE - 8-10	W - 10-15	N - 5-10
Soil Condition	Dry on surface	Dry on surface	Very dry on surface	Damp on surface
Burner Pressure	40 PSI	40 PSI	40 PSI	40 PSI
Ground Speed	3 MPH	3 MPH	3 MPH	3 MPH

Effect of Various Combinations of Flame Application on the Growth and Production of Corn Plants

The primary objective of this study was to measure the effect of various flame treatments upon the yield of corn. This effect was evaluated from two points of view--(1) the effect of flame upon the corn plant itself (as measured by yield) and (2) the effect of flame cultivation upon yield under field conditions. These findings and evaluations were obtained in the two experiments described under the section on procedure. An observation of the effect of accumulative flaming on corn height was also made and the findings discussed.

Effect of Flame upon the Corn Plant. The results of this experiment are shown in Table 11. Analysis of this data shows no significant difference in yield between flame treatments at the ninety-five per cent confidence level. That is, two flamings did not reduce the yield as compared to one flaming and etc. The ten to fifteen bushels per acre average increase in yield of the flame treatments over the chemical check plots, although significant at the ninety-five per cent level, is believed to be due to a blocking effect that was significant in these plots. Although not significant at the above stated levels, the ranking of these treatments in order of yield shows a definite correlation between yield and the number of flamings. This ranking may also be seen in Table 11. Yields are expressed in bushels per acre and were obtained by multiplying the actual harvested yields, in pounds, by 242 (harvested rows represented 1/242 of an acre) and dividing by 72 (pounds of ear corn per bushel). Actual plot yields may be seen in Table 24 of the Appendix.

Moisture content of all plots were not taken but random sampling throughout the test area indicated no significant

Table 11. Yield and order of ranking of treatments showing effect of flaming on corn plants.

Treatment	Plot No.	Yield (Bu./Acre)	Plot No.	Yield (Bu./Acre)	Plot No.	Yield (Bu./Acre)	Ave. Yield (Bu./Acre)	Ranking By yield
1. 2-4"		105.9	8	118.0	16	130.0	118.0	5
2. 2-4"+8-10"		103.2	12	117.0	18	133.9	118.1	4
3. 2-4"+8-10" +14-16"		120.0	10	119.6	15	119.2	119.6	1
4. 8-10"		96.2	9	115.3	20	121.0	110.8	7
5. 8-10"+14-16"		108.5	14	112.2	19	136.4	119.1	2
6. 2-4"+14-16"		116.2	13	113.4	21	117.0	115.4	6
7. 14-16"		95.8	11	138.9	17	121.4	118.7	3
8. Chemical Only (Check)		90.9		104.8		106.8	100.8	8

difference in grain moisture between treatments. A stalk count of the harvested rows, just prior to harvesting, revealed an average population of approximately 19,000 stalks per acre. There was no significant difference in population between treatments and the stand was almost identical to the plant count made in the early part of the growing season. Although the same rows were not used in all instances for these two population counts, the data would indicate a very low plant mortality rate due to flame cultivation. Data for the latter stalk count may also be seen in Table 25 of the Appendix.

Observations of the effect of flame treatments on plant height was made several times throughout the growing season. There was a definite stunting of the plants due to flaming. However, this effect was not of a permanent nature. Table 12 presents data to show how the plant height was affected. Stunting appeared to be accumulative, in that plants receiving three flamings were retarded more than those receiving only one or two flamings. This stunting, although apparent throughout most of the growing season, gradually disappeared and could not be distinguished after the latter part of July.

Effect of Flame Cultivation upon Yield under Field Conditions. Results of this experiment show a range of thirty bushels per acre difference in yield between the "no flame-no cultivation" treatment and the various flame treatments. Yield results for each treatment and their respective ranking is presented in Table 13. There is a definite correlation between the

Table 12. Effect of accumulative flame applications on height of corn plants.

Date	Normal corn height (Inches)	One flaming		Two flamings		Three flamings	
		Height: (In.)	Reduction (Inches)	Height: (In.)	Reduction (Inches)	Height: (In.)	Reduction (Inches)
May 10	2 - 4	2 - 4	0	2 - 4	0	2 - 4	0
May 23	8 - 10	6 - 8	2	6 - 8	2	6 - 8	2
June 11	14 - 16	14 - 16	0	10 - 12	4	10 - 12	4
June 27	36 - 38	36 - 38	0	33 - 35	3	31 - 33	5
July 10	52 - 54	52 - 54	0	52 - 54	0	50 - 52	2
August 1	72 - 76	72 - 76	0	72 - 76	0	72 - 76	0

Table 13. Yield and order of ranking of treatments showing effect of flaming under field conditions.

Treatment	Plot No.	Yield (Bu./Acre)	Plot No.	Yield (Bu./Acre)	Plot No.	Yield (Bu./Acre)	Ave. Yield (Bu./Acre)	Ranking
1. Pre-emergence	5	97.0	15	97.4	27	97.0	97.1	11
2. Pre+2-4"	8	101.1	22	134.4	31	105.0	113.5	3
3. Pre+2-4"+8-10"	12	119.2	20	116.5	34	130.2	121.9	1
4. Pre+2-4"+8-10"+14-16"	2	87.2	14	101.1	30	119.6	102.6	9
5. Pre+8-10"	6	102.8	18	91.0	37	113.6	102.5	10
6. 2-4"	10	93.7	23	91.1	39	105.8	96.8	12
7. 2-4"+8-10"	4	96.6	26	121.9	35	128.8	116.4	2
8. 2-4"+8-10"+14-16"	1	101.5	25	119.6	28	111.0	110.7	5
9. 2-4"+14-16"	9	101.1	19	105.0	33	130.1	112.1	4
10. 8-10"	11	97.4	21	123.2	36	107.6	109.4	7
11. 8-10"+14-16"	13	125.3	16	80.7	38	125.3	110.4	6
12. No Flame-No Cult.	7	88.0	24	75.0	32	114.5	92.5	13
13. Normal Cultivation	3	96.6	17	97.8	29	116.2	103.5	8

number of flamings and yield. This is graphically expressed by the curve in Figs. 21 and 22. The reduction in yield due to the fourth flame application is believed to be primarily due to the testing procedure used.

Although no significant difference in yield resulted between the various flame treatments, the thirty bushel per acre increase in yield of treatment number three (three flamings - pre-emergence + 2-4 inch + 8-10 inch) over the "check" plot (no cultivation + no flaming) was significant at the ninety per cent confidence level. None of the other treatments were significantly higher than the "check" plot at this level.

There was a definite blocking effect in these plots. However, this factor did not alter the results of this test. As discussed in the previous section, a stalk count of the harvested rows showed an average population of approximately 19,000 stalks per acre with no significant difference between plots. Also, there was no significant difference in grain moisture content between treatments. Tables 26 and 27 of the Appendix show the actual plot yields and stalk count for each of the various treatments.

Even though not significant at the ninety per cent confidence level, the following observations and evaluations are worth noting. Analysis of the data in Table 13 indicates that the application of flame at the 14-16 inch stage has a detrimental effect upon yield, particularly when the crop has received two or more previous flamings and is expressed graphically

EXPLANATION OF PLATE XIII

Fig. 21. Graph showing the relationship of the number of flamings and yield. Values are averages for all treatments with the same number of applications.

Fig. 22. Graph showing the relationship of accumulative flame applications and yield. The dotted line shows the result when flaming treatments were started at the 2-4 inch height.

PLATE XIII

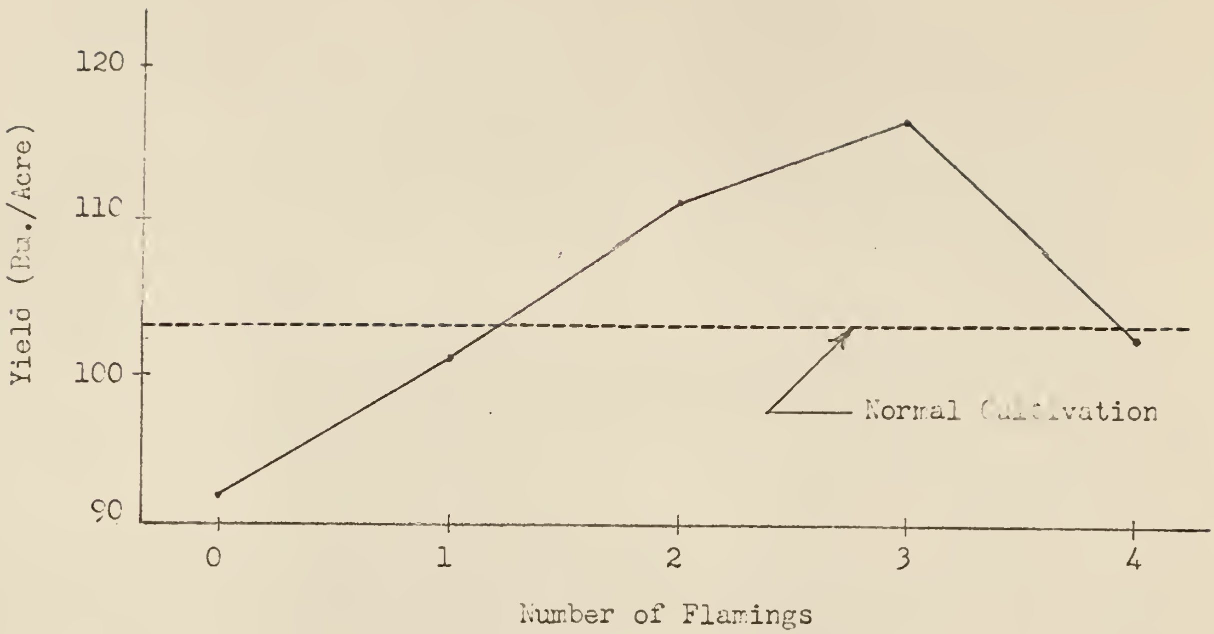


Fig. 21

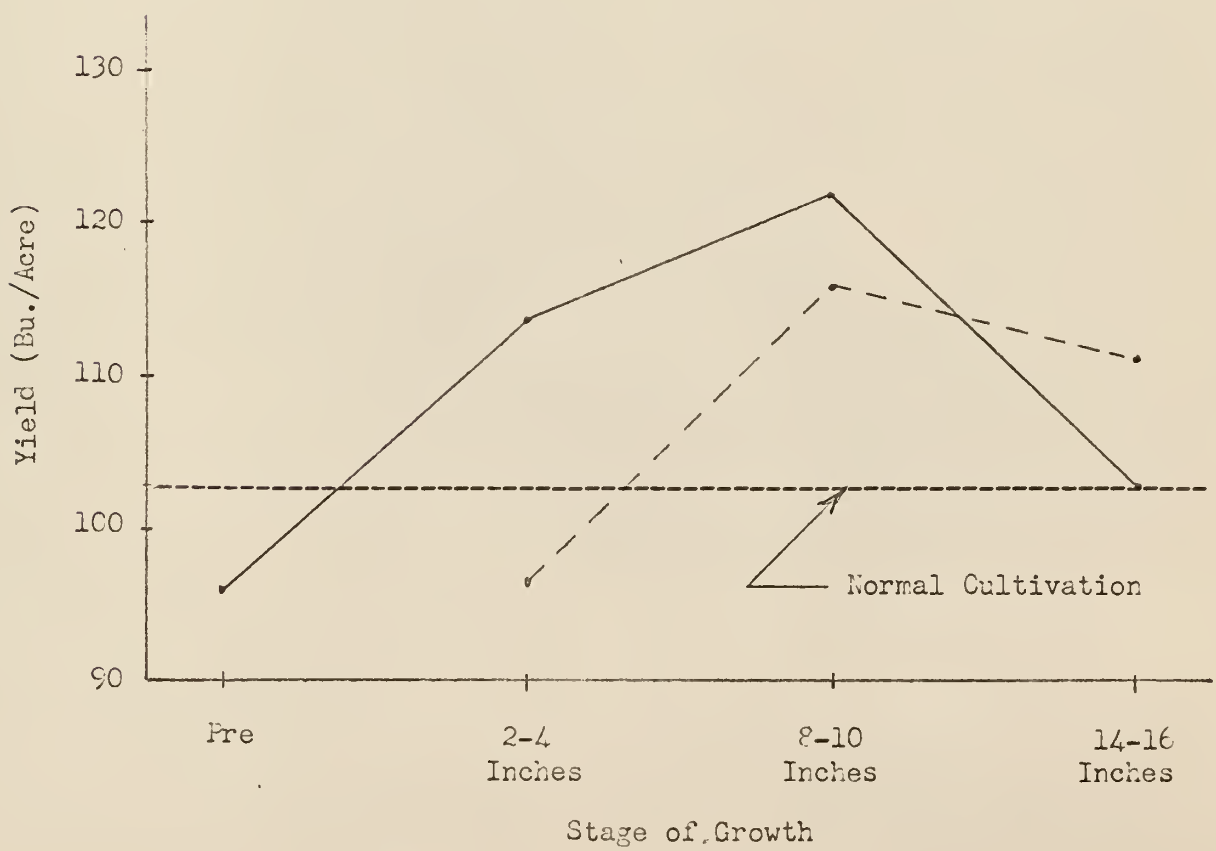


Fig. 22

in Fig. 22.

Flame application at the 8-10 inch height does not appear to be detrimental to yield, even though visual observations of the effect of this flaming stage would indicate otherwise. In fact, yields for all but one of the treatments involving the 8-10 inch flaming were higher than similar treatments without the 8-10 inch application. The bar graphs in Figs. 23 and 24 show these comparisons for both tests--(1) under field conditions and (2) with the weed factor eliminated. These two findings are somewhat contrary to results published by other researchers.

The pre-emergence flame treatment by itself, like all of the other single flame application treatments, showed very little benefit in regard to yield. But, it is interesting to note that the first and third ranking treatments included pre-emergence applications. However, it is the 2-4 inch application, when coupled with one or more other flamings, that is really effective in improving yields. This flame application stage is common in all of the five top rankings.

No significant difference in yield resulted between the various flame treatments and the normal cultivation plots. Any combination of two or more flame treatments did, in general, improve yields over normal cultivation. The graph in Fig. 22 shows the comparison of number of flamings (averaged collectively) versus yield.

Other variables such as ground speed, burner pressure and

EXPLANATION OF PLATE XIV

Fig. 23. Bar-graph showing the effect upon yield of an added 8-10 inch flame application to several flame treatments.

Fig. 24. Bar-graph showing effect on yield when an 8-10 inch flame application was added to several flame application treatments. These results are from the plots received a chemical weed killer to eliminate the weed factor.

PLATE XIV

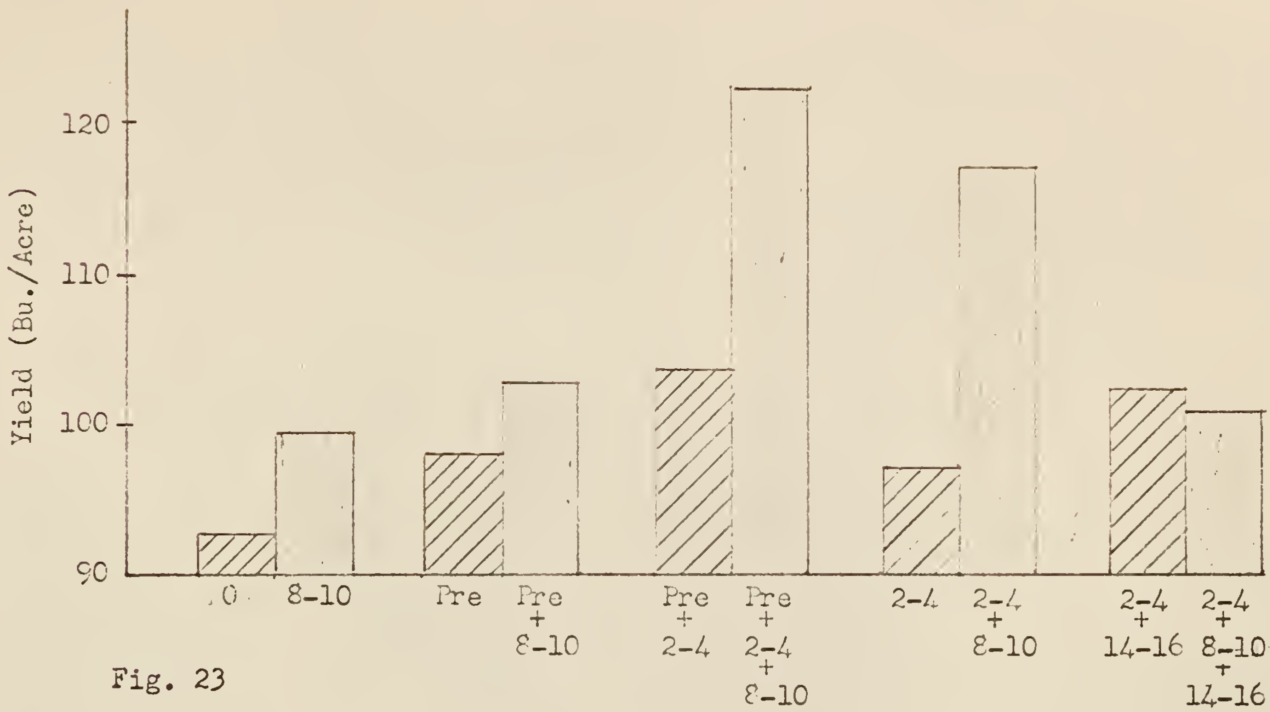


Fig. 23

Stage of Flame Applications

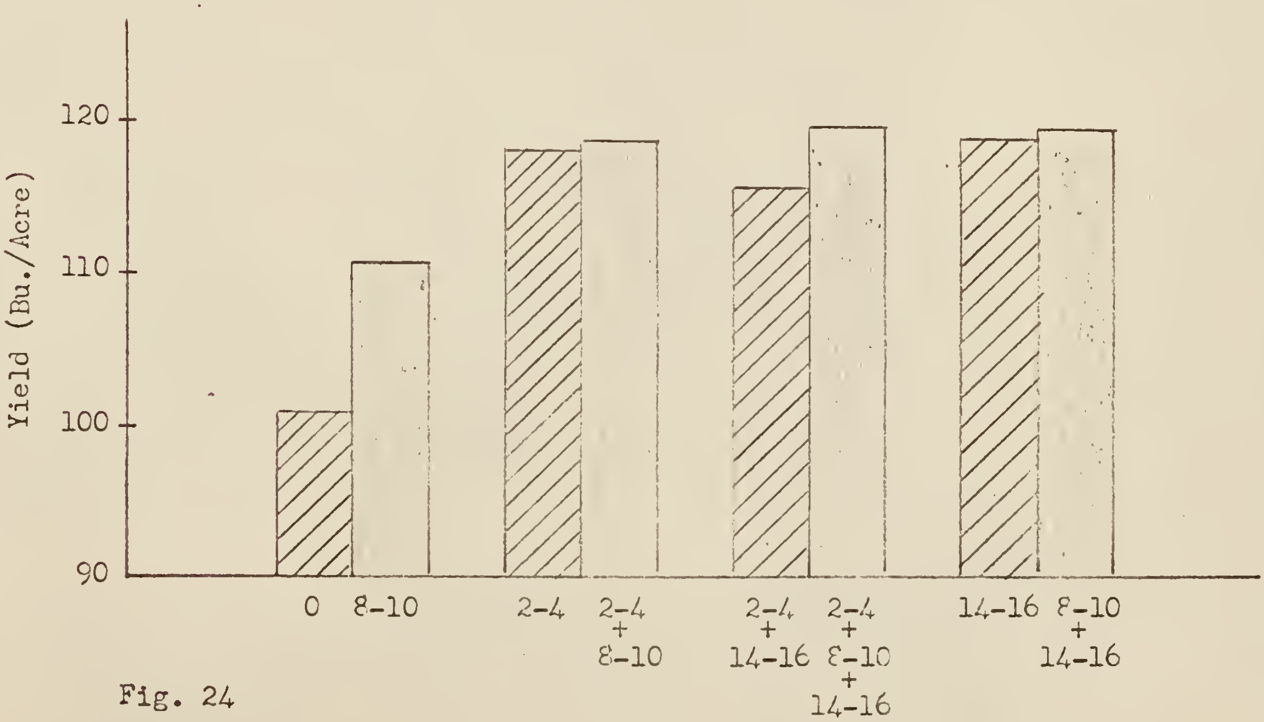


Fig. 24

Stage of Flame Applications

burner setting were held constant for all treatments. Although adjustment of these variables will influence the effectiveness of flame applications (this is discussed in more detail in a latter section), it would not be expected to alter the relative results as discussed here. Only further research can bear this out.

The statistical values computed and used in making these comparisons may be found in Tables 28 and 29 of the Appendix. Plates XIX and XX of the Appendix, also present some sample calculations to show how these values were obtained. The limited number of observations available for most of these statistical tests had a great influence in the confidence levels at which the results are significant.

Effect of Various Flame Treatments on Control of Weed Growth

The results of this experiment reveal not only a significant reduction (ninety-five per cent confidence level) in weed growth for all treatments as compared to the "no flame-no cultivation" treatment, but also there are significant differences between the various flame treatments in their ability to control weeds. Weed populations for each plot as well as the average population for each treatment is shown in Table 14.

Only a cautious comparison between weed control results and yields should be made with the data from these tests. Even though the same sets of plots were used for both experiments, the expressed weed populations are only for the sixteen-inch

Table 14. Weed population of plots for various weed control treatments.

Treatment	Plot number and population (Two rows) No.	Population	No.	Population	No.	Population	Average Population (per row)
1. Pre-emergence	5	40 - 57	15	35 - 40	27	71 - 108	58.50
2. Pre+2-4"	8	29 - 37	22	25 - 28	31	38 - 51	34.67
3. Pre+2-4"+8-10"	12	65 - 65	20	35 - 16	34	33 - 35	41.50
4. Pre+2-4"+8-10"+ 14-16"	2	4 - 3	14	10 - 4	30	25 - 0	7.67
5. Pre+8-10"	6	37 - 41	18	30 - 27	37	101 - 79	52.50
6. 2-4"	10	50 - 99	23	49 - 72	39	102 - 170	90.33
7. 2-4"+8-10"	4	48 - 31	26	61 - 136	35	59 - 23	59.67
8. 2-4"+8-10"+14-16"	1	4 - 4	25	5 - 4	28	5 - 15	6.17
9. 2-4"+14-16"	9	2 - 17	19	10 - 24	33	21 - 11	14.17
10. 8-10"	11	122 - 156	21	47 - 42	36	57 - 96	86.67
11. 8-10"+14-16"	13	19 - 5	16	10 - 4	38	22 - 11	12.83
12. No flame-no cultivate	7	82 - 72	24	152 - 149	32	48 - 82	97.50
13. Normal cultivation	3	39 - 50	17	54 - 23	29	55 - 53	45.67

control bands over the drill area and do not reflect total weeds in the plots. Also, this method of weed control evaluation takes into account only the number of weeds and not the size or type. These factors could have a very great effect upon the resulting yields.

There was considerable difference in the size of weeds within the various plots. In general, plots receiving the 14-16 inch application had fewer small weeds while those plots not receiving the early flame applications tended to have more large weeds. No actual differentiation between weed size was made. The plots with the larger weeds usually had fewer in number. This may have been due to the shading effect of the large weeds or the competition for moisture and nutrients. It should be noted that the higher ranking control plots not only had fewer weeds in number but that they were, on the average, smaller in size as well. The weed count was made during the week of July 17-24. In order to be consistent, only weeds of one-inch height or over were counted. It was concluded that smaller weeds would be of little economic importance at this date. Table 15 shows how treatments ranked, from one to thirteen, in order of their ability to control weeds (thirteen being the highest). Rankings are shown for the over-all test and within each of the three blocks. The lines below the rankings indicate the treatments for which their were no significant differences. These tests were made at the ninety-five per cent confidence level and the statistical values and computations for this table

Table 15. Ranking of treatments for ability to control weed growth.

	Ranking												
	1	2	3	4	5	6	7	8	9	10	11	12	13
							Block No. 1						
Treatment Number	10	12	6	3	1	13	7	5	2	11	9	8	4
Weed Count	139.0	77.0	74.5	65.0	48.5	44.5	39.5	39.0	33.0	12.0	9.5	4.0	3.5
							Block No. 2						
Treatment Number	12	7	6	10	13	1	5	2	3	9	11	4	8
Weed Count	150.5	98.5	60.5	44.5	38.5	37.5	28.5	26.5	25.5	17.0	7.0	7.0	4.5
							Block No. 3						
Treatment Number	6	5	1	10	12	13	2	7	3	11	9	4	8
Weed Count	136.0	90.0	89.5	76.5	65.0	54.0	44.5	41.0	34.0	19.5	16.0	12.5	10.0
							Over-All						
Treatment Number	12	6	10	7	1	5	13	3	2	9	11	4	8
Weed Count	97.3	90.3	86.7	59.7	58.5	52.5	45.7	41.5	34.7	14.2	12.8	7.7	6.2

may be seen on Plates XXI and XXII of the Appendix.

Several observations may be made from these data. The four top-ranking treatments are the same regardless of whether the blocks are considered separately or collectively. Although the order of ranking is switched, the same treatments appear in the top four positions in all comparisons. In evaluating this, only one common factor seems to appear--the 14-16 inch flame application. In fact, only four treatments included a 14-16 inch flaming and these are the four top-ranking treatments. From the over-all comparison, these four treatments were significantly more effective in controlling weeds than the other flame treatments as well as the "normal cultivation" plots.

The "normal cultivation" treatment consistently ranked near the middle in all of the blocks. Single flame application treatments, regardless of stage of growth, had little ability to control weed growth and consistently ranked at the bottom in all of the tests.

Effect of Burner Pressure and Ground Travel on Temperatures and Thermal Patterns

The method employed in this study to measure flame temperatures is dependent upon the specific heat of the material upon which the temperature-sensitive indicator is applied. Therefore, it is readily admitted that the temperatures measured are not absolute or necessarily those experienced by a plant exposed to these same conditions. It is believed, however, that these measurements are valid for the existing conditions and do provide relative values that are sufficient for measuring and determining the effect of burner pressure and ground travel upon the induced temperatures and thermal pattern.

Temperature measurements were recorded for six temperature levels (200-400-500-600-700°F.). Plotting isothermal lines for all temperatures tended to present a cluttered picture. By using only three temperature levels (200-400-600°F.) the same patterns and effects could be shown with much less confusion. Therefore, only three temperature levels were used in constructing the thermal patterns shown.

The time interval required for the transfer of heat from the applied flame to the cells of the plants is difficult to determine. It was assumed to be in proportion to the magnitude of the temperature gradient between the cells and the surrounding flame. Thus, it is important not only to know something of the shape of these patterns but the temperature levels and exposure time as well. With this in mind Tables 16 and 17 were developed to show the heat energy applied at various values of ground travel and burner pressure and the actual exposure time for these rates of ground travel. The cross-section of the effective flame is approximately 8-10 inches wide, and this value is used in computing the given exposure intervals. Two burners were used on each row.

Lethal temperatures for most small plants is around 150-200°F. The exposure time required at these temperatures may

Table 16. Effect of rate of travel and burner pressure on amount of heat applied (BTU per foot of row).

Operating pressure PSI	BTU per foot of row for various ground speeds			
	2 MPH	3 MPH	4 MPH	5 MPH
30	115	77	58	46
40	155	103	78	62
50	176	117	88	70

Table 17. Effect of ground travel and flame pattern width on exposure time.

Ground travel MPH	Exposure time in seconds for various widths (Two burners per row)				
	12 in.	14 in.	16 in.	18 in.	20 in.
1	.68	.79	.91	1.02	1.13
2	.34	.40	.45	.51	.57
3	.28	.33	.37	.42	.47
4	.17	.20	.23	.25	.28
5	.14	.16	.19	.21	.23

range from one-fourth to three-quarters of a second. These values will depend upon the type, age and condition of the plant. A higher rate of energy (heat) application will normally reduce the transfer time from flame to cell and thereby shorten the necessary exposure time.

Even though the method used in this study measures only the maximum temperatures existing within each zone, the exposure time is reflected in these measurements as will be noted in the experiment on ground travel. The method does provide a reasonably reliable method of measuring the effective control areas induced by any given set of ground travel and burner pressure values.

Results from this study show that these two variables do have a pronounced effect upon the temperature levels and pattern of the applied flame. This, in turn, has an important value in developing effective application techniques. These results also show that burner pressure and ground travel, although independent of each other, are correlated and may be adjusted in combination to produce a range of desired thermal patterns.

This study demonstrates that it is not only possible to calibrate the rate of energy release (BTU per foot of row) for any combination of these values but that the resulting thermal patterns are proportional in size and temperature level and that similar energy rates produced similar patterns regardless of the values of these variables.

Effect of Rate of Ground Travel on Induced Flame Pattern. The isothermal diagrams on Plate XV show the measured thermal patterns for the three tested ground speeds--1, 2, and 3 M.P.H. The faster rate of ground travel reduced the size of the thermal zones as well as the over-all measured patterns. Although the induced pattern extends beyond the measurement zone in most cases, comparison of the diagrams indicate that the higher rates of travel not only flatten out the various thermal zones but,

EXPLANATION OF PLATE XV

Fig. 25. Measured flame pattern for the "Stoneville" burner when operating at 40 PSI burner pressure and 3 MPH ground travel. The angle of the burner is 30 degrees with the horizontal.

Fig. 26. Measured flame pattern for the "Stoneville" burner when operating at 40 PSI burner pressure and 2 MPH ground travel. Reduction in pattern size may be noted.

Fig. 27. Measured flame pattern for the "Stoneville" burner when operating at 40 PSI burner pressure and 3 MPH ground travel. Pattern size is reduced even further.

PLATE XV

Burner Pressure - 40 PSI

Ground Travel - 1 MPH

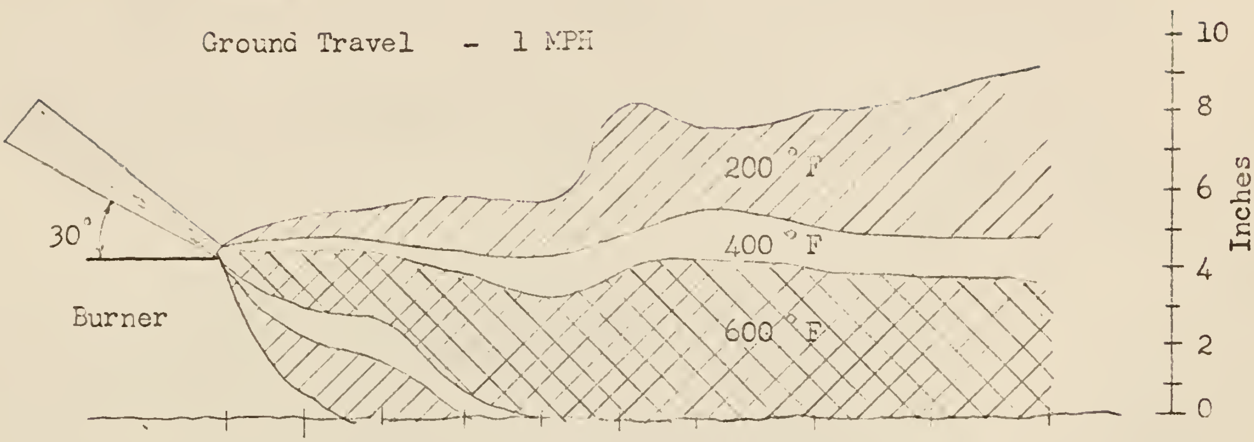


Fig. 25

Burner Pressure - 40 PSI

Ground Travel - 2 MPH

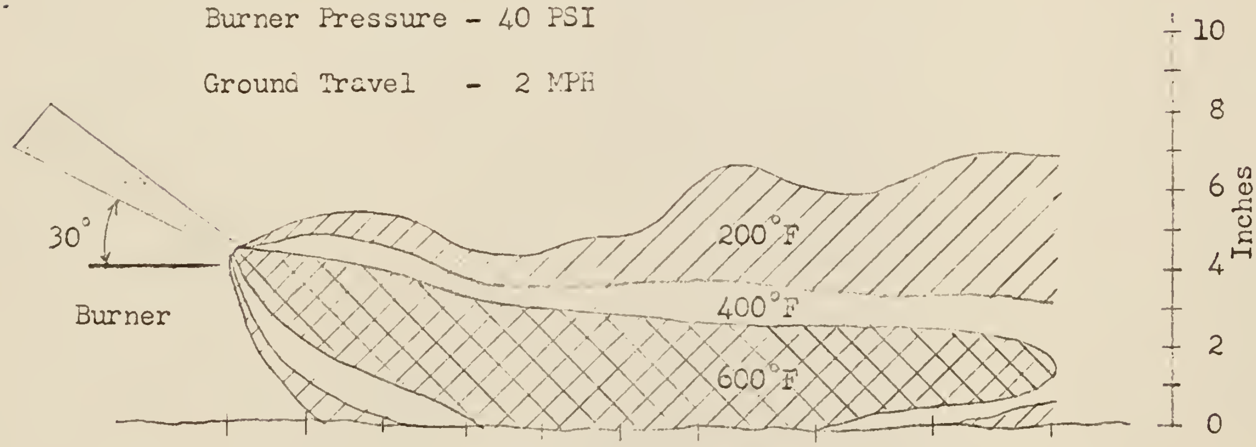


Fig. 26

Burner Pressure - 40 PSI

Ground Travel - 3 MPH

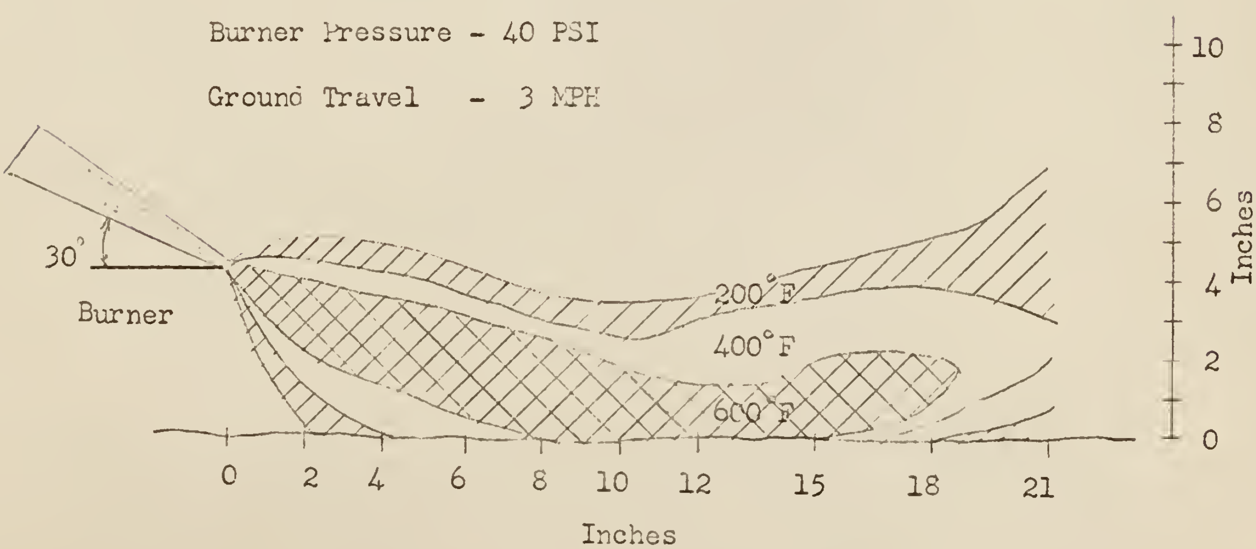


Fig. 27

shorten them as well. This is due to the difference in exposure time which determines the rate of energy (heat) applied for any given operating pressure.

Another observation noted in this experiment was the irregular shape of the pattern at the slower ground speeds. There appears to be a more marked "bounce" effect at the lower speeds. The surface of row area, where these tests were made, was raked flat before each test and is felt not to be a factor. Again, the longer exposure time for these slower rates of travel is one probable cause for this irregularity in shape of pattern at these speeds.

Effect of Burner Pressure on Induced Flame Pattern. From viewing the diagrams on Plate XVI, which shows the isothermal patterns for the burner pressures tested (30, 40, and 50 P.S.I. at 3 M.P.H.), it appears that variations in burner pressure do not have as great an effect upon the induced temperature pattern as does ground travel. It should be remembered that the rate of ground travel was doubled when increased from one to two miles per hour, whereas, the pressure was only increased by one-third when varied from 30 to 40 P.S.I. Likewise, a look at Table 16 shows that BTU per foot of row for changes in burner pressure does change at a lower rate than when changes with the rate of travel, especially at the 3 M.P.H. or above speeds. Therefore, variations in burner pressure do have an important effect upon the temperature level and temperature pattern.

Another observation made from these diagrams is that the

EXPLANATION OF PLATE XVI

Fig. 28. Measured flame pattern for "Stoneville" burner when operating at 30 PSI burner pressure and 3 MPH ground travel.

Fig. 29. Measured flame pattern for "Stoneville" burner when operating at 40 PSI burner pressure and 3 MPH ground travel.

Fig. 30. Measured flame pattern for "Stoneville" burner when operating at 50 PSI burner pressure and 3 MPH ground travel. Notice that the various burner pressures have very little effect on the over-all size of the pattern but that the average temperature within the pattern does increase with the higher pressures.

PLATE XVI

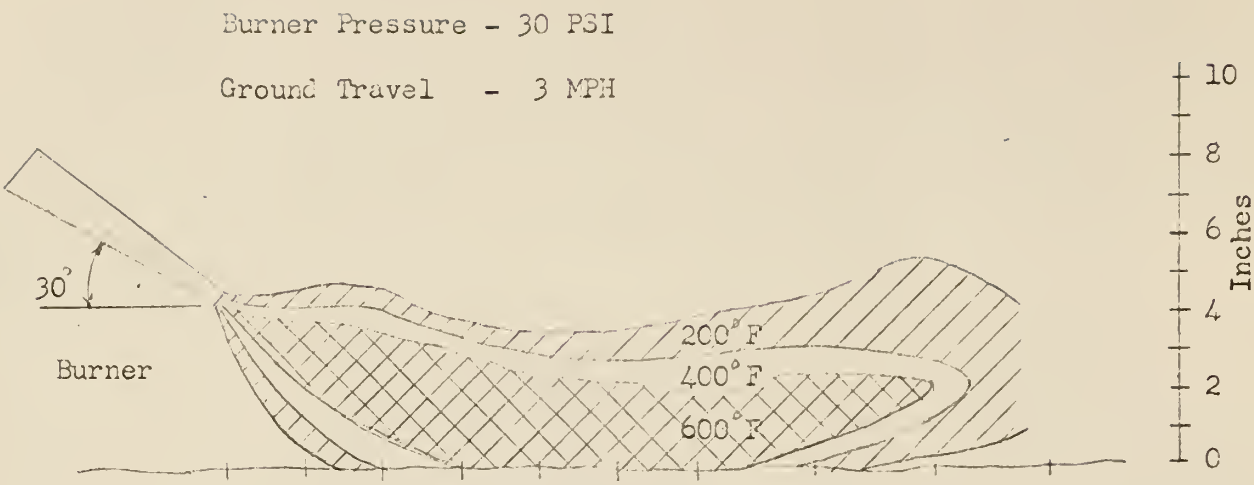


Fig. 28

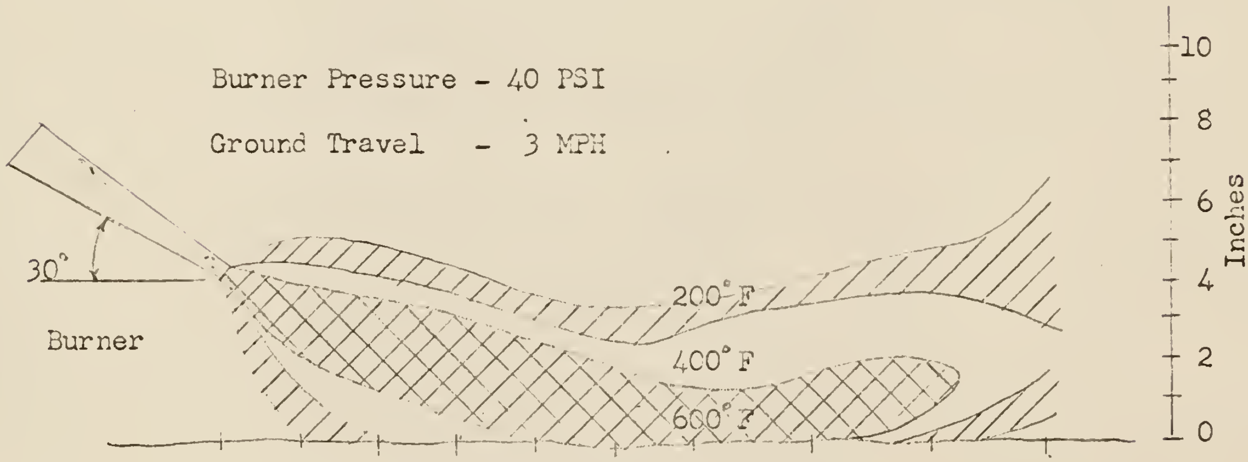


Fig. 29

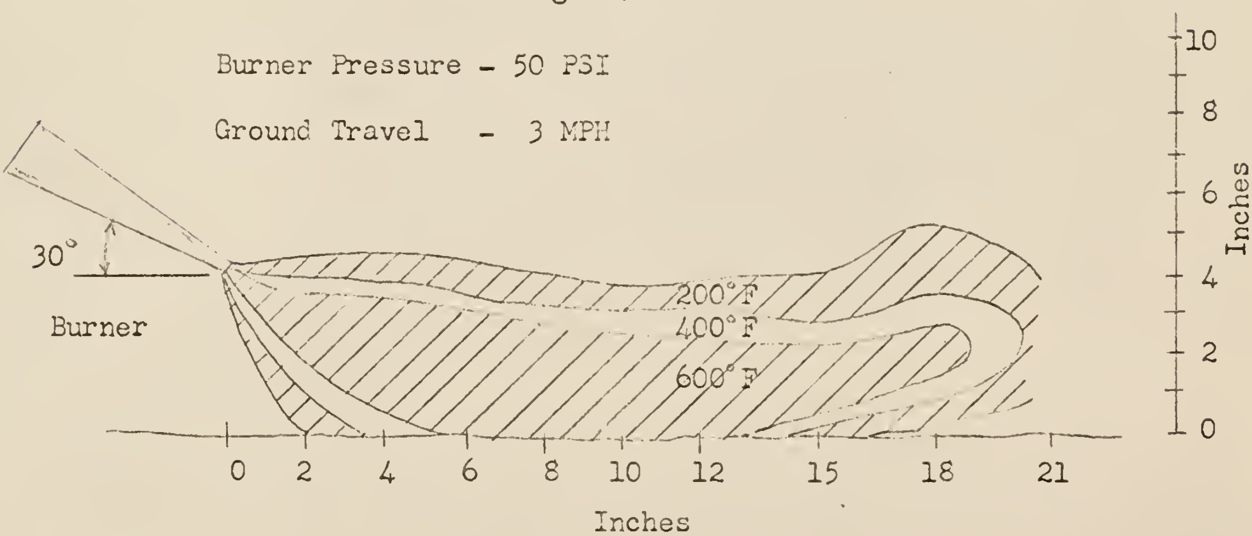


Fig. 30

width of the pattern (would appear as length on the diagram) does not change greatly with variation in pressure. The size of the higher temperature zones does however, become larger with the higher burner pressure. This means that although the induced flame patterns are not greatly altered, the average temperature within this pattern is increased considerably with the higher pressure.

Energy Application Rate (BTU per Foot of Row) as Guide for Applying Flame. Although the exposure time is varied with the three ground speeds used in this test, the higher average temperature associated with increased burner pressure acted as a compensating factor that resulted in similar thermal patterns being plotted from the three similar heat application rates tested--1.5 M.P.H.; 30 P.S.I.; 2 M.P.H.; 40 P.S.I.; 2.25 M.P.H. and 50 P.S.I. Plate XVII shows these temperature patterns as measured. If the "bounce" effect which seems to be associated with the slower ground speeds is neglected, these induced patterns are almost identical. From these results, it appears that BTU per foot of row is a fairly reliable method of calibrating the burners and selecting values for the two variables--ground speed and burner pressure.

Economic Aspects of Flame Cultivation

Although a two-row flame cultivator was used in all phases of this study, cost figures for two-, four- and six-row machines have been calculated. This was considered desirable

EXPLANATION OF PLATE XVII

Fig. 31. Measured flame pattern for the "Stoneville" burner when operating at 30 PSI burner pressure and 1.5 MPH ground travel. This selection of variables provides an application of 153 BTU per foot of row.

Fig. 32. Measured flame pattern for the "Stoneville" burner when operating at 40 PSI burner pressure and 2.0 MPH ground travel. This selection of variables provides an application of 157 BTU per foot of row.

Fig. 33. Measured flame pattern for the "Stoneville" burner when operating at 50 PSI burner pressure and 2.25 MPH ground travel. This selection provides an application of 156 BTU per foot of row. Note the almost identical flame patterns if the "bounce" effect of the slow ground speeds are neglected.

PLATE XVII

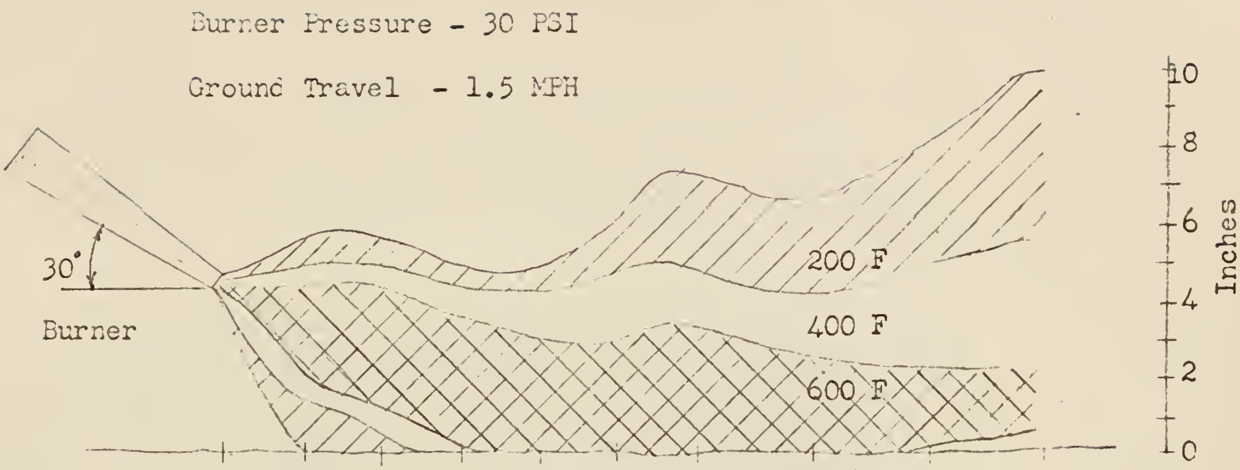


Fig. 31

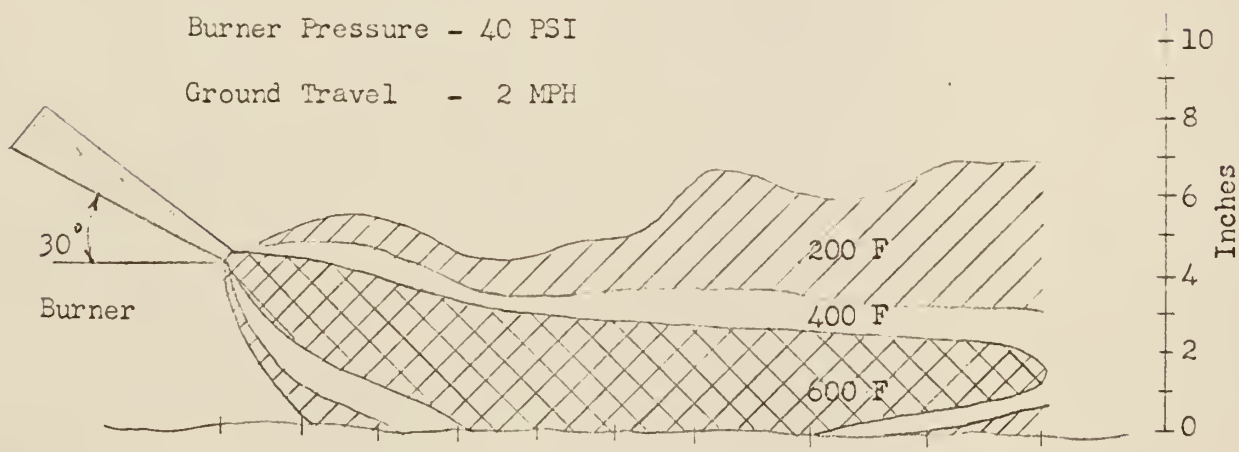


Fig. 32

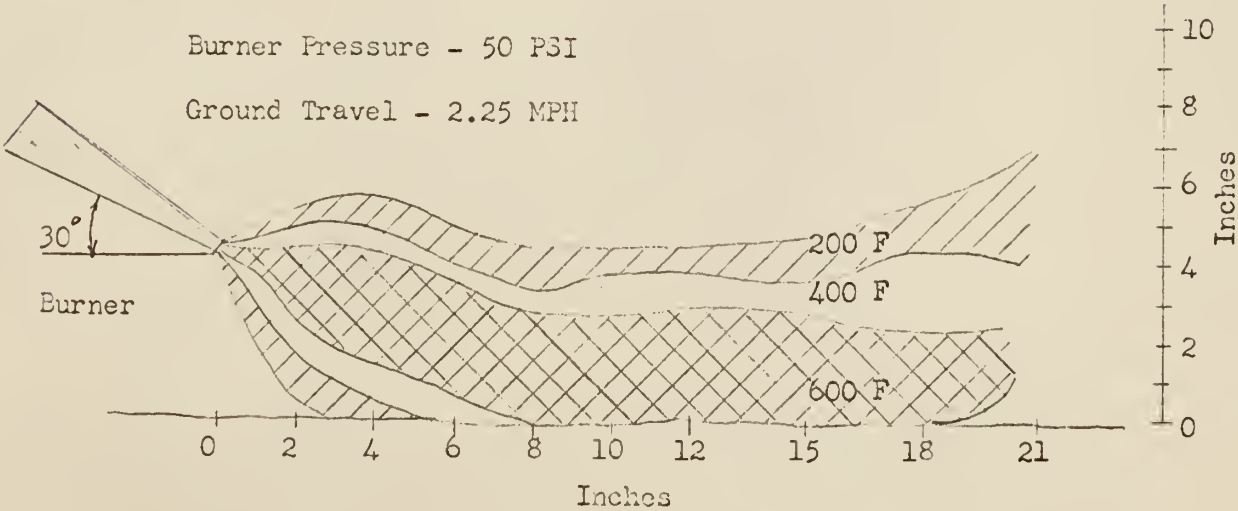


Fig. 33

as the size of farming operations in Kansas require large equipment and this size of tool is in common use throughout the state. Also, even though only one burner pressure and one rate of ground travel was used in all the plot work, these two variables do greatly affect (1) the flame application effectiveness as shown by the study on flame patterns and (2) the cost of application as will be shown later in this discussion. Cost figures for several combinations of these variables were computed and are discussed even though their effectiveness has not been field tested.

Total costs per acre will vary depending upon the number of applications, size of equipment, rate of ground travel and burner pressure used. The manner in which these variables affect the cost of operation will be discussed in the following sections. Based on the application techniques used in this study for weed control--3 mph, 40 psi and a total of three applications (optimum)--costs were $5.94, $4.26, and $3.81 per acre respectively for two-, four- and six-row machines. These cost figures compare very favorably with costs for conventional or chemical weed control practices.

To be able to express costs on an hourly or per acre basis it was necessary that some standard size of operation be assumed. Darley and Suter (6) recommend an annual usage level of 200 hours for tractor-mounted shovel cultivators. This level was considered applicable to flame cultivators and was the size of operation used to compute ownership costs.

It is admitted that this level of operation is probably somewhat high for the four- and six-row machines, but it was deemed important to avoid introducing another variable into these computations. The graph in Fig. 34 illustrates how the cost of operation per acre (actual acres harvested) varies with the size of operation and the size of equipment used.

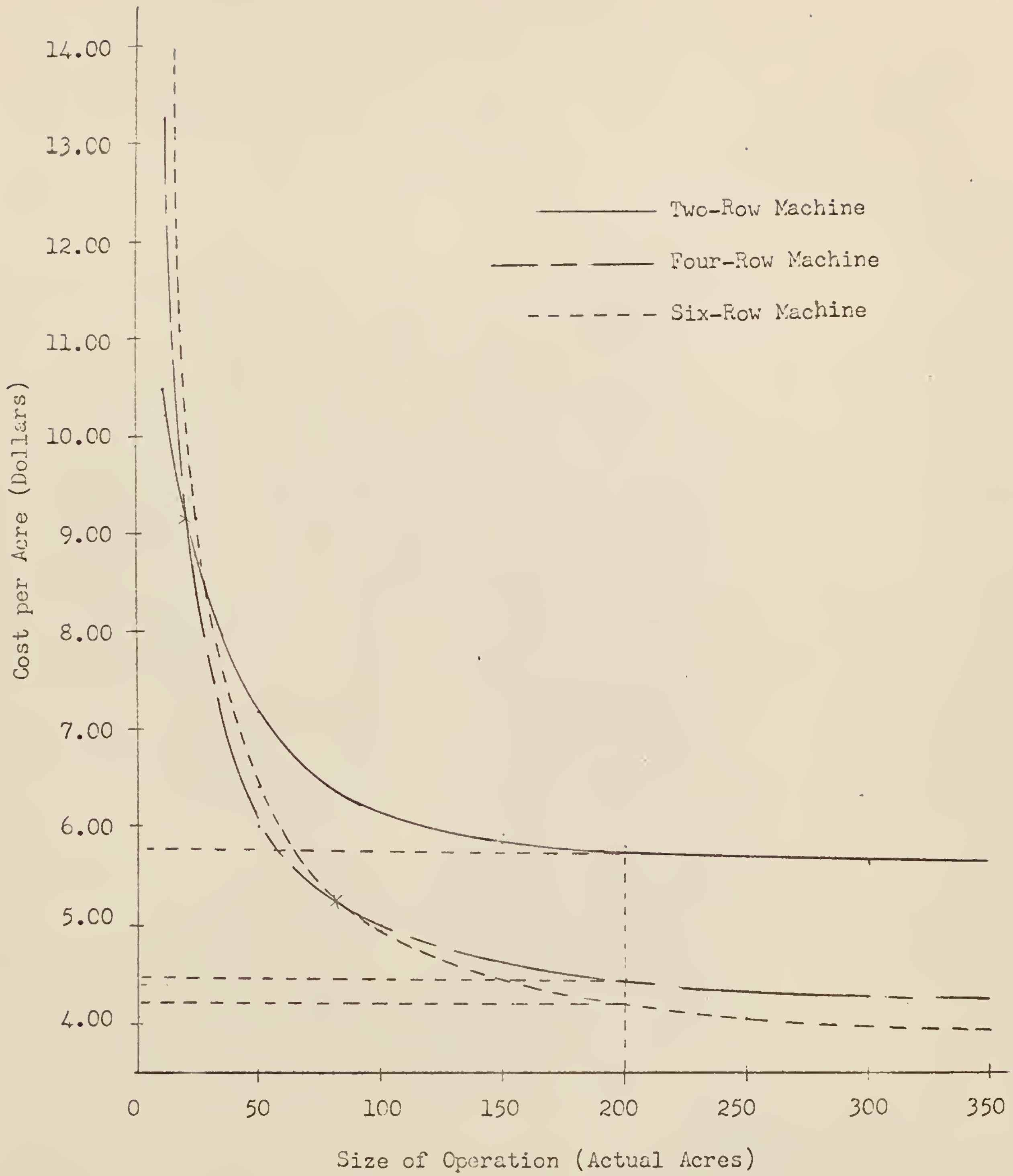
It is important to note that the 200-hour per year level (standard size of operation), which would be approximately 150, 300 and 450 acres respectively for two-, four-, and six-row equipment, is well into the flat portion of the curves and indicate an economical size of operation. The four-row and six-row machines could be operated at only a 200 and 250 acre level at approximately the same per acre cost. Again, the difference in cost per acre for the three sizes of machines are shown by the dotted lines on the graph.

Another point worth noting is the size of operation at which it would be economically advisable to change from two-row to four-row equipment or from four-row to six-row machines (where curves cross). As may be seen, these occur at rather small acreages, 20 and 80 acres respectively. Therefore, it would appear advisable for most farmers to consider the larger sized machines when purchasing a flame cultivator. Since, a six-row machine might involve a complete retooling of planting and tillage equipment, the four-row machine would seem to be the optimum for most operations.

Table 18 shows the operational and investment cost used in

EXPLANATION OF PLATE XVIII

Fig. 34. Graph illustrates the effect of size of operation, and size of equipment upon the cost of flame cultivation. Note that the points where the size of operation would warrant going to the next larger size of machine is where the curves cross--change from two-row to four-row at 20 acres and from four-row to six-row at 80 acres. Neither of these occur in the flat portion of the curves which would indicate an economical size of operation.



Three Flame Applications per Year - 3 MPH and 40 PSI

Fig. 34

Table 18 Cost of Flaming Per Acre As Affected By Size of Operation and Size of Equipment

Ac. per Yr.	Machine Acres (Ax3)	Two-Row Machine				Four-Row Machine				Six-Row Machine			
		Hrs. per Yr.	Cost per Acre			Hrs. per Yr.	Cost per Acre			Hrs. per Yr.	Cost per Acre		
			Opertnl.	Invest.	Total		Opertnl.	Invest.	Total		Opertnl.	Invest.	Total
12	36	15	5.36	5.10	10.46	10	3.88	9.35	13.23	5	3.46	12.16	15.62
25	75	35	5.36	3.35	8.71	15	3.88	4.50	8.38	10	3.46	5.84	9.30
50	150	70	5.36	1.67	7.03	35	3.88	2.25	6.13	20	3.46	2.92	6.38
100	300	135	5.36	.84	6.20	65	3.88	1.12	5.00	45	3.46	1.46	4.93
150	450	200	5.36	.56	5.92	100	3.88	.75	4.63	65	3.46	.97	4.44
200	600	270	5.36	.42	5.78	135	3.88	.56	4.44	90	3.46	.73	4.20
250	750	345	5.36	.33	5.69	165	3.88	.45	4.33	110	3.46	.56	4.05
300	900	400	5.36	.28	5.64	200	3.88	.37	4.25	135	3.46	.49	3.96

constructing the graph and also the annual hours of operation and the machine acres (the number of acres multiplied by the number of flame applications) for all three sizes of machines. These costs are based on an operating ground speed of three miles per hour and a burner pressure of forty pounds per square inch.

Operational Costs. Cost of operation makes up the major portion of the total cost of flame cultivation. Two items, in particular, account for over fifty per cent of this total cost--labor and fuel for the flame cultivator. Tractor costs are another sizeable item. Table 19 presents a complete breakdown of these costs on a per hour basis. These costs are also expressed on a machine-acre basis. Machine-acre refers to an individual application per acre rather than the total number of acres involved in a unit.

Annual repair and maintenance costs were computed at 3.5 per cent of the initial machine cost. This is the rate recommended by the American Society of Agricultural Engineers for most field machines. Fuel costs for the flame cultivator were determined from the fuel consumption test conducted. Data from these tests are shown in Table 20.

Labor costs were arbitrarily set as $1.25 per hour, the standard minimum wage level. Tractor costs were derived from data by Fortson (10) and consisted of computing ownership costs on the basis of normal usage levels and tractor fuel costs on a ten horsepower per hour per gallon rate. A load factor

Table 19. Operational costs per hour and machine acre (burner pressure--40 psi).

	(1)Mainten-ance and repair	(2)Fuel for flame cult.	Labor	(3)Tractor costs	Total operating cost: Per hr.	Total operating cost: Per machine acre (4)
2-Row	$.097	$1.78	$1.25	$ .825	$3.95	$1.79
4-Row	.131	3.56	1.25	.90	5.84	1.29
6-Row	.170	5.34	1.25	1.05	7.81	1.16

(1) Computed at 3.5% of initial cost of equipment.
(2) Ten Cents/gallon.
(3) Computed from Chart (See Appendix).
(4) Cost per application per acre.

Table 20. Fuel costs for three operating pressures.

Operating pressure	Fuel consumed: lb/hr	Fuel consumed: (1)gal/hr	Cost of fuel: (2)per gal.	Cost of fuel: per hour	Cost per acre (3)
psi					
30	55.0	12.80	.10	1.28	.58
40	75.5	17.78	.10	1.78	.81
50	85.5	20.10	.10	2.01	.91

(1) 4.25 lb/gal (Propane fuel)
(2) Average price in Manhattan, Kansas over last five years.
(3) Based on three MPH ground travel (2.2 acres/hour).

consistent with the size of equipment being used was employed in estimating these fuel costs.

Ownership Costs and Total Costs. Depreciation is the largest single item making up annual ownership costs. For this study the useful life was estimated at ten years and a straight-line method was used to compute depreciation charges. Annual interest costs were computed at six per cent of the average value over the ten-year life. The remainder of the ownership costs is composed of insurance, taxes and shelter. These were computed on the basis of two per cent of the initial value, a method approved by the American Society of Agricultural Engineers.

Table 21 presents the annual costs for two-, four- and six-row machines together with a computation of these costs on an hourly and machine-acre basis. It should be noted how small these investment costs are in comparison to the operating costs. This accounts for the fact that even small sized operations can well afford to use the larger machines. Total ownership costs expressed on an hourly and machine-acre basis are shown in Table 22. Here again, it is worth noting the savings per acre are obtained with the larger equipment--particularly between the two- and four-row equipment.

Effect of Rate of Travel and Burner Pressure on Cost of Operation. Data in Table 23 show how fuel costs vary with the burner pressure and the rate of ground travel. It may be observed that the variance in fuel costs due to changes in operating pressure becomes less as the rate of ground travel is increased. Likewise, the savings in fuel costs due to faster ground speeds become greater as the operating pressure is increased.

Table 24 show how these factors affect the total cost per operation. These variances are not nearly as great as when the fuel costs are considered alone.

Table 21. Total flaming costs per hour and machine acre. (40 psi--3 mph)

	Operational costs: Per hour	Per machine acre	Ownership costs: Per hour	Per machine acre	Total costs: Per hour	Per machine acre
2-row	3.95	1.79	.42	.19	4.37	1.98
4-row	5.84	1.29	.56	.13	6.40	1.42
6-row	7.81	1.16	.73	.11	8.54	1.27

Table 22. Ownership costs per hour and machine acre. (Burner pressure--40 psi)

	(1) Initial cost	(2) Deprec.	(3) Interest	(4) Insur. Taxes & Shelter	Total	(5) Cost per hour	(6) Cost per machine acre
2-row	$558.00	$55.80	$16.74	$11.16	$ 83.70	$.42	$.19
4-row	748.90	74.89	22.47	14.98	112.34	.56	.13
6-row	973.50	97.35	29.21	19.47	146.03	.76	.11

(1) Average value for two commercial brands of equipment.
(2) Based on ten year life (straight-line method).
(3) 6% of average value over useful life.
(4) 2% of initial value.
(5) Assuming 200 hours per year.
(6) Operating at 3 mph.

Table 23. Effect of rate of travel and operating pressure on fuel costs per machine acre.

Operating pressure (PSI)	Fuel cost per machine acre (dollars) 2 MPH	3 MPH	4 MPH	5 MPH
30	.88	.58	.46	.37
40	1.23	.81	.63	.49
50	1.40	.91	.72	.56

Table 24. Effect of rate of travel and burner pressure on total cost per machine acre.

Operating pressure (PSI)	Operating cost per machine acre (dollars) 2 MPH	3 MPH	4 MPH	5 MPH
30	1.82	1.24	.99	.80
40	1.94	1.29	1.02	.82
50	2.00	1.31	1.04	.83

SUMMARY AND CONCLUSION

Continued research and study is needed to verify and refine the results obtained in this study. However, a few conclusions can be made and several other indications are apparent from the observation and findings of this one year's work. The following findings and conclusions are expressed in terms of actual field application.

Effect of Various Combinations of Flame Applications on the Growth and Production of Corn Plants

The results of this study verifies the general conclusion of earlier research in the Cotton Belt states--that moderate flame applications do not seriously harm the corn plant or reduce yields. Variations in yield between the various flame treatments were not significant at the ninety per cent level. However, results from the test under field conditions did show a definite relationship between yield and the number of flame applications.

Treatment No. 3 (three flamings--Pre-emergence + 2-4 inch

+ 8-10 inch) was the only treatment to significantly increase yields over the "no flame-no cultivation" treatment (ninety per cent confidence level). None of the flame treatments significantly improved yields over the "normal cultivation" treatment even though several treatments increased yields by 10-20 bushels per acre.

One flaming, regardless of stage of application, had little ability to improve yields. Although two applications did produce slightly higher yields than normal cultivation, three flamings was the most effective rate and produced an average increase of 12.8 bushels per acre over conventional tillage methods. No benefit was received from the fourth application. In fact, yields were reduced in the single treatment using four flamings.

Flame applications at the 8-10 weeks height did not reduce yields even though there was severe retarding effects upon the plant. The 14-16 inch flame application, which had little apparent effect upon plant growth, did however, show a tendency to lower yields when compared to other flame treatments. These effects were not significant and may be due, in part, to the growing conditions that prevailed.

It can not be concluded, from one year's study, that flame cultivation was effective in improving yields over conventional methods. However, it can be concluded that the use of flame to control weeds in corn had no lasting detrimental effects upon the plant and that yields were as good or better than normal cultivation practices.

Effect of Various Flame Treatments on Control of Weed Growth

The timeliness of flame applications were much more critical in controlling weeds than they were in affecting yields. There was a definite relationship between the number of flamings and the per cent weed reduction. Again, a single flame application was only slightly effective in controlling weeds, and, although two or more flamings had better weed control than normal cultivation, it is much more meaningful when these treatments are viewed individually.

There was considerable variation between the various treatments in their ability to control weeds. There is a significant difference (95 per cent confidence level) between several of the treatments, but only four appear significantly better than "normal cultivation" in all comparisons. Here, there is no correlation between weed control and the number of flamings as these range from two to four applications. Only the 14-16 inch flame application appears consistently in these top four rankings.

Although the ability to control weed growth by the use of flame was shown to be effective, it would be hazardous to try and rank the importance of the various flame application stages without recognizing the rainfall, temperature, and other growing conditions. The importance or benefit of any one flaming could depend entirely upon these existing growing conditions as well as the variety, stage of growth, and size of the weed cover at the time of treatment.

In conclusion, it may be stated from the results of this phase of the study, that flame cultivation can be effective in controlling weed growth in corn production and that effective weed control can be attained by three flaming applications if they are applied at the proper time and according to recommended flame cultivation techniques.

Effect of Burner Pressure and Ground Travel on Temperatures and Thermal Patterns

The effect of these two variables upon the induced temperatures and thermal patterns is not only quite measurable, but also is of importance in developing improved flame application techniques. Ground speed and burner pressure are easily controlled by the operator and can be selected and varied almost continuously throughout the normal operating ranges.

In general, the faster the rate of ground travel the smaller the effective flame pattern--both in length and height. The relative size of the various thermal zones do not change greatly with different rates of ground speed, which means the average temperatures within the induced pattern is fairly consistent. Only the size of the pattern varies.

This over-all reduction in pattern size is due to the increasingly limited exposure time associated with the faster ground speeds. This, in turn, corresponds to the reduced energy application rate (BTU's per foot of row).

This characteristic has some rather important aspects which may be used in developing effective application techniques for various cropping programs. In other words, the rate of travel influences the length of the flame pattern (width of control area over the row) and slower ground speeds could be employed to control broader areas. Also, since the height of the induced pattern is related to the ground speed, control of this variable would allow the proper selection of ground speeds for improved effectiveness in controlling taller weeds or grasses or the application of a narrower pattern for early weed control or more sensitive crops.

Variations in burner pressure, on the other hand, appears to have only slight effect upon the over-all size of the flame pattern. It does, however, alter the relative size of the thermal zones within the induced flame pattern--the higher the pressure the higher the average temperatures within the flame.

It is apparent from this work that variation in burner pressure does not effect the measured temperature pattern as greatly as changes in ground travel. This could be predicted from the computed energy application values (BTU's per foot of row) for variations in burner pressure. It should be noted that the variation in ground speed is of a larger relative magnitude than the corresponding variation in burner pressure. This, in part, explains the difference in response to variations in these two variables.

Again, the manner in which variations in burner pressure affects the applied flame pattern has some important aspects in developing effective flame application techniques. For example, weeds that are particularly resistant to control by flame (heat) could be exposed to a higher average temperature for any pre-determined exposure time (rate of travel) by increasing pressure without greatly affecting the size of the control area or desired height of the induced pattern. This could be particularly important in narrow-row plantings or low growing crops.

One of the more important findings of this phase of the study was that there appears to be a fairly reliable relationship between the rate of energy application (BTU's per foot of row) and the measured temperature patterns. Furthermore, that this relationship is not greatly affected by the adjustment of these two variables--rate of ground travel and burner pressure--so long as they are combined to produce similar energy application levels.

Information of this kind is of real practical value in developing effective flame application techniques. Selection of the proper burner pressure would be a function of the tractor speed for any given energy application level (or vice-versa) and one or both of these variables could be adjusted to obtain the desired energy application level and most effective application pattern.

Further research should be able to determine the most effective energy application levels for various stages of weed growth, size and variety. This would allow operators to not only plan and carry out effective "preventive" weed control programs, but also to develop more effective techniques to eliminate serious weed infestations or carry through salvage programs which might result from an abnormally wet season or other reasons for inability to perform timely weed controlled practices as planned.

Economic Aspects of Flame Cultivation

The results of this study indicate that flame cultivation is economically feasible for controlling weeds in corn production. Annual per acre costs for effective flame cultivation techniques compare very favorably with both chemical and conventional tillage methods in common use to day. The total cost per acre for flame cultivation depends upon the number of applications required, size of equipment, and the rate of ground travel and operating pressure used. The size of operation, also, plays an important role in determining total costs, especially for the smaller sized units.

In general, two-row flame equipment would not be recommended for use on most Kansas farms. For any size of operation that would be economically feasible (at least forty acres) a substantial savings (approximately $1.00/acre) could be attained by larger equipment, four- or six-row machines. Likewise, a small savings could be made by using six-row equipment in operations of over 80-100 acres. However, this might involve a retooling of other equipment which could prove to be more expensive.

Fuel costs for any selected rate of heat application (BTU's per foot of row) is independent of the ground speed and burner pressure employed. Costs such as labor and tractor costs are usually computed on an hourly basis and do vary greatly with the ground travel rates selected. Whenever possible, a maximum ground speed conducive to effective and desired application techniques should be used.

Increasing the burner pressure independently of ground speed does increase the fuel costs per flame application, especially at the slower ground speeds. The increase is not nearly so great when viewed in the light of the over-all costs per application.

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RECOMMENDATIONS FOR FURTHER STUDY

This investigation indicated several areas where further study is needed. The plot work employed in this investigation needs to be continued for at least two additional years to obtain sufficient data and observation for a more reliable evaluation. In particular, the factor of weather and growing conditions as they affect both yield and weed growth requires these additional observations over a several-year study.

Continued research is needed in determining and evaluating the effects of ground travel and burner pressure on the applied heat pattern. The effect of wind and shape of seed bed are important factors affecting the efficiency of flame application that should be explored.

Very little information is available on the temperatures required to kill weeds, the exposure time or most susceptible time to control weeds by the use of flame. Such information concerning several general classes of weeds are needed before really effective and efficient flame application techniques can be developed.

When reliable answers to the above stated problems are found, this knowledge should be assembled and used to develop more effective flame cultivation techniques--not only for general weed control and eradication but also for special weed infestation such as Johnson grass, black amber cane, foxtail, ragweed, bindweed, and the other species which are particularly difficult to control. In all instances, where possible, these techniques should be incorporated with other proven weed control practices and methods.

REFERENCES

(1) Arle, H. F.
Johnson Grass Control with Dalpon. Arizona Agricultural Experiment Station Bulletin 293:1-13, 1958.

(2) Barnes, Harris, Jr.
Hoe Must Go. Crops and Soils, 12:21-22, August, 1960.

(3) Carter, L. M., R. F. Colwick, and J. R. Tavernetti.
Evaluating Flame-Burner Design for Weed Control in Cotton. Transactions ASAE 3:2, pp. 125-28. 1960.

(4) Colwick, R. F.
Weed Control Equipment and Methods for Mechanized Cotton Production. Southern Cooperative Service, Bulletin No. 71. April, 1960.

(5) Cruz, S. R.
Experiments on Weeding by Flame. Aranta Journal of Agriculture. 6 (1), 51:57, 1956.

(6) Darley, R. D., and R. C. Suter.
"How Much Do You Use Your Farm Machinery?", The Farm Outlook. College of Agriculture, University of Missouri, November, 1952.

(7) Edmondson, V. W., and J. H. White.
Costs of Chemical and Flame Control of Weeds in Cotton. University of Arkansas Agricultural Experiment Station. Bulletin No. 569. April, 1956.

(8) Edwards, F. L.
Personal Letter. Associate Professor, Department of Agricultural Engineering, University of Arkansas. November, 1962.

(9) Epp, A. W.
Cost of Operating Machinery on Nebraska Farms. University of Nebraska Agricultural Experiment Station, Bulletin 413. September, 1952.

(10) Fortson, J. C.
Break-Even Points for Harvesting Machines. Georgia Agricultural Experiment Station Bulletin No. N. S. 66. December, 1959.

(11) Gates, F. C.
Weeds in Kansas. Kansas State Board of Agriculture Yearbook. 1941.

(12) Hedges, T. R., and W. R. Barley.
Economics of Mechanized Cotton Harvesting. California Agricultural Experiment Station Bulletin 743. 1954.

(13) Holstun, J. T., Jr., O. B. Wooten, C. G. McWhorter, and G. B. Crowe.
Weed Control Practices, Labor Requirements and Costs in Cotton Production. Weeds, 8:2. April, 1960.

(14) Hoover, L. M.
Farm Machinery--To Buy or Not to Buy. Kansas State University Agricultural Experiment Station Bulletin 379. March, 1959.

(15) Klingman, G. C.
Weed Control: As a Science. John Wiley and Sons, New York, 1961.

(16) Knake, E. L.
Results of Flame Cultivation Trials in Illinois, 1961. Department of Agronomy, Extension Service in Agriculture and Home Economics. College of Agriculture, University of Illinois, 1962.

(17) Larson, G. H., G. E. Fairbanks, and F. C. Fenton.
What does it cost to use Farm Machinery. Kansas State University Agricultural Experiment Station Bulletin 417. April, 1960.

(18) Matthews, E. J. and Tupper Co.
Early Flame Cultivation of Cotton, Arkansas Farm Research, Volume 10-3. May-June, 1962.

(19) McKibben, E. G.
Capacity of Field Machine, Agricultural Engineer Yearbook, American Society of Agricultural Engineers, 1960.

(20) McWharter, C. G., O. B. Wooten, and G. B. Crave.
An Economic Evaluation of Weed Control Practices in the Delta. Mississippi State College Agricultural Experiment Station Circular 203. March, 1956.

(21) Parker, R. E., O. B. Wooten, and E. B. Williamson.
Field Evaluation of Two-Types of Flame Burner Mountings. United States Department of Agriculture, ARS 42-60. February, 1962.

(22) Price, D. and T. C. Longnecker.
The Use of Flame to Control Weeds in Row Crops. High Plain Research Foundation, Plainview, Texas.

(23) Reed, A. D.
Machinery Costs and Related Data. University of California, Extension Service, 1954.

(24) Scoville, Orlin J., Lewis B. Nelsen, and Green Shields, Elco L. Land and Advances in Technology. Land--U. S. Department of Agriculture Yearbook. 1958.

(25) Smilie, J. L.
Flame for Weed Control. Louisiana Agriculture. Louisiana State University Agricultural Experiment Station. Spring, 1959.

(26) Stanton, H. S.
A New Flame Cultivation for Cotton. Arkansas Farm Research, Volume III, Bo. 1, Spring, 1954.

(27) Stephenson, K. O.
Mechanized Weed Control in Cotton. Arkansas Agricultural Experiment, Arkansas Farm Research, Volume 10:3. May-June, 1962.

(28) Tavernetti, J. R., and H. F. Miller.
Studies in Mechanization of Cotton Farming in California. California Agricultural Experiment Station Bulletin No. 747. November, 1954.

(29) Tupper, G., and E. J. Mathews.
Early Flame Cultivation in Cotton. Arkansas Agricultural Experiment Farm Research 11:4. May, 1962.

(30) Williamson, E. B., V. B. Wooten, and F. E. Fulgham.
Flame Cultivation, Mississippi State College Agricultural Experiment Station Bulletin 545. July, 1956.

(31) Losses in Agriculture.
United States Department of Agriculture, ARS 20-1. 1954.

APPENDIX

Table 25. Actual yield of chemical plus various flame treated plots (pounds).

Treatment (Addition to chemical)	1st Replication		2nd Replication		3rd Replication		Average yield for treatment
	Plot No.	Yield	Plot No.	Yield	Plot No.	Yield	
1. 2-4"	2	30.62	8	34.12	16	37.62	34.12
2. 2-4"+8-10"	6	29.87	12	37.87	18	38.75	34.15
3. 2-4"+8-10"+ 14-16"	1	34.75	10	34.62	15	34.50	34.62
4. 8-10"+14-16"	4	31.37	14	32.50	19	39.62	34.50
5. 2-4"+14-16"	7	33.62	13	32.87	21	33.87	33.58
6. 8-10"	5	27.75	9	33.37	20	35.00	32.05
7. 14-16"	3	27.62	11	40.37	17	35.12	34.37

Table 26. Stalk count at harvest time for various plots (chemical & flame treated).

Treatment (Addition to chemical)	1st Replication		2nd Replication		3rd Replication		Average plant population
	Row 2	Row 3	Row 2	Row 3	Row 2	Row 3	
1. 2-4"	34	40	39	34	42	40	38.16
2. 2-4"+8-10"	35	38	37	40	39	44	38.81
3. 2-4"+8-10"+ 14-16"	34	33	39	34	41	43	37.33
4. 8-10"	37	32	34	39	39	44	37.50
5. 8-10"+14-16"	35	38	39	35	42	36	37.50
6. 2-4"+14-16"	37	38	40	37	44	41	39.50
7. 14-16"	40	37	39	39	40	36	37.66

Table 27. Actual yield of various flame treated plots (pounds).

Treatment	1st Replication		2nd Replication		3rd Replication		Average Yield
	Plot No.	Yield	Plot No.	Yield	Plot No.	Yield	for treatment
1. Pre-emergence	5	28.25	15	27.37	27	27.25	27.62
2. Pre+2-4"	8	29.12	22	38.75	31	30.25	32.72
3. Pre+2-4"+8-10"	12	34.50	20	33.75	34	37.62	35.32
4. Pre+2-4"+8-10"+ 14-16"	2	25.12	14	29.12	30	34.62	29.62
5. Pre+8-10"	6	29.62	18	26.50	37	32.75	29.62
6. 2-4"	10	27.00	23	26.25	39	30.50	27.92
7. 2-4"+8-10"	4	28.12	26	35.12	35	37.12	33.41
8. 2-4"+8-10"+14-16"	1	29.50	25	34.62	28	32.00	32.08
9. 2-4"+14-16"	9	29.12	19	30.25	33	37.50	32.31
10. 8-10"	11	27.37	21	35.50	36	31.00	31.29
11. 8-10"+14-16"	13	36.12	16	23.25	38	36.12	31.82
12. No Cultivation	7	25.37	24	21.62	32	33.00	26.67
13. Normal Cultivation	3	28.12	17	28.50	29	33.50	30.08

Table 28. Stalk count at harvest time for various flame treated plots.

Treatment	1st Replication Row 2	1st Replication Row 3	2nd Replication Row 2	2nd Replication Row 3	3rd Replication Row 2	3rd Replication Row 3	Average yield population
1. Pre-emergence	42	43	31	44	41	38	39.81
2. Pre+2-4"	44	48	41	37	36	38	40.80
3. Pre+2-4"+8-10"	41	39	40	35	44	42	40.16
4. Pre +2-4"+8-10"+ 14-16"	36	39	41	39	33	53	40.16
5. 2-4"	42	38	38	45	40	33	39.16
6. 2-4"+8-10"	43	36	43	45	44	42	42.00
7. 2-4"+8-10"+14-16"	33	54	45	33	33	52	41.80
8. Pre+8-10"	41	37	38	43	37	45	40.12
9. 2-4"+14-16"	43	37	42	33	44	31	38.33
10. 8-10"+14-16"	43	40	42	44	42	42	42.16
11. 8-10"	40	43	36	35	35	41	38.33
12. No Cultivation	36	39	37	37	31	38	36.33
13. Normal Cultivation	49	45	42	44	44	47	45.12

EXPLANATION OF PLATE XIX

Statistical analysis and sample calculations for determining significance of variations in yield for the various flame treatments. Results show no significant difference in yield between the several flame treatments. However, there was a significant increase in yield from flaming over the non-flamed plots. Test was made at the ninety-five per cent confidence level.

PLATE XIX

Table 29. Statistical analysis of yield results for experiment to determine effect of flame on corn plants.

Source of variation	d.f.	Ss	Ms	F	Sig
Blocks	3	1,452.8960	484.2987	8.45	***
Treatments	7	1,151.9297	164.5614	2.87	*
*(Orth. Comp.)	1	927.0647	927.0647	16.17	***
(Remainder)	6	224.8650	37.4775	.65	ns
Error	21	1,204.2865	57.3470		
Total	31	3,809.1122			

N = 32

*Comparison of T_8 with all others together.

Total S = 3,682.1
SS = 427,492.25
-C = 423,683.1378
Ss = 3,809.1122

Blocks SS/8 = 425,136.0338
-C = 423,683.1378
Ss = 1,452.8960

Treatments SS/4 = 424,835.0675
-C = 423,683.1378
Ss = 1,151.9297

T = 455.7

$$\frac{(\quad T)^2}{4(56)} = \frac{207,662.49}{224} = 927.0647$$

EXPLANATION OF PLATE XX

Statistical analysis and sample calculations to determine significance of yield results for various flame treatments.

I	=	Flame vs Normal cultivation
II	=	Pre-emergence flame application vs no pre-emergence flaming
III	=	8-10 inch flaming vs no 8-10 inch flaming (pre-emergence)
IV	=	8-10 inch flaming vs no 8-10 inch flaming (no pre-emergence)
V	=	Pre + 2-4" + 8-10" vs "No flame-no cultivation"

PLATE XX

Table 30. Statistical analysis of yield results for flame and non-flamed plots.

Source of variation	d. f.	Ss	Ms	F	Sig
Blocks	2	1631.18	815.59	4.90	Yes
Treatments	12	2584.86	215.40	1.29	No
I	1	66.44	66.44	.40	No
II	1	109.03	109.03	.66	No
III	1	107.53	107.53	.65	No
IV	1	535.82	535.82	3.22	No
V	1	668.65	668.65	4.02	Yes
Remainder	7	1097.39	156.77	.942	
Error	24	3993.98	166.42		
Total	38	8210.02			

N = 39

Total S = 4,166.9
SS = 453,416.57
-C = 445,206.55
Ss = 8,210.02

Blocks SS/13 = 446,837.73
-C = 445,206.55
Ss = 1,631.18

Treatments SS/3 = 447,791.41
-C = 445,206.55
Ss = 2,584.86

EXPLANATION OF PLATE XXI

Statistical analysis and sample calculations to determine significance of variations in ability to control weed growth as the various flame treatments. There was a significant variation between treatments at the ninety-five per cent confidence level.

PLATE XXI

Table 31. Statistical analysis weed population various flame treatments.

Source of variation	d.f.	Ss	Ms	F	Sig
Treatments	12	71,805.87	5,983.82	19.32	Yes
Blocks	2	1,643.87	821.94	2.65	No
T. x B.	24	37,136.13	1,547.34	5.00	Yes
Error		12,078.50	309.71		
Total	77	122,664.37			

N = 78

Total S = 3,647.
SS = 293,185.
-C = 170,520.63
Ss = 122,664.37

Treatments SS/6 = 242,326.50
-C = 170,520.63
Ss = 71,805.87

Blocks SS/26 = 172,164.50
-C = 170,520.63
Ss = 1,643.87

Treatment x
Block SS/2 = 281,106.50
-C = 170,520.63
-T Ss = 71,805.87
-B Ss = 1,643.87
Ss = 37,136.13

EXPLANATION OF PLATE XXII

Statistical analysis to determine ranking of the various flame treatments in their ability to control weed growth in the drill area. Duncan's New Multiple range test is the test procedure used. The ranking of the various treatments, both by the individual blocks and the overall results, are shown on the lower part of the page.

PLATE XXII

Duncan's new multiple range test

Treatment Number	Rp	P	B_1	B_2	B_3
2	29.49	3.055	29.53	37.48	45.50
3	31.02	3.200	30.93	39.25	47.55
4	32.01	3.289	31.79	40.35	48.87
5	32.72	3.348	32.36	41.07	49.75
6	33.27	3.389	32.75	41.57	50.36
7	33.71	3.419	33.04	41.94	50.81
8	34.06	3.442	33.27	42.22	51.15
9	34.34	3.458	33.42	42.42	51.39
10	34.59	3.470	33.54	42.57	51.56
11	34.81	3.478	33.61	42.66	51.68
12	34.98	3.484	33.67	42.74	51.77
13	35.14	3.488	33.71	42.79	51.83

Ranking
(Left to right--poorest to best weed control)

B_1

10	12	6	3	1	13	7	5	2	11	9	8	4
139.0	77.0	74.5	65.0	48.5	44.5	39.5	39.0	33.0	12.0	9.5	4.0	3.5

B_2

12	7	6	10	13	1	5	2	3	9	11	4	8
150.5	98.5	60.5	44.5	38.5	37.5	28.5	26.5	25.5	17.0	7.0	7.0	4.5

B_3

6	5	1	10	12	13	2	7	3	11	9	4	8
136.0	90.0	89.5	76.5	65.0	54.0	44.5	41.0	34.0	19.5	16.0	12.5	10.0

Over-all

12	6	10	7	1	5	13	3	2	9	11	4	8
97.5	90.3	86.7	59.7	58.5	52.5	45.7	41.5	34.7	14.2	12.8	7.7	6.2

USE OF FLAME AS A MEANS TO CONTROL WEEDS IN CORN PRODUCTION

by

LYNDELL WORTH FITZGERALD

B. S., Kansas State University, 1951, 1959

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1963

The purpose of this study was to determine (1) the effect of flame on the growth and yield of corn plants, (2) the effectiveness of flame in controlling weed growth, (3) the effect of rate of ground travel and burner pressure on flame application patterns and (4) the economic feasibility of flame cultivation as a weed control practice in corn production in Kansas.

Measuring and evaluating the effect of various flame applications on the corn plant and the ability to control weeds was accomplished by the use of replicated treatments in randomly located field plots. One set of plots received an application of a pre-emergence weed killer prior to the flame treatments to eliminate the weed factor. These plots were evaluated in terms of yield and plant height. Another set of plots received only the flame treatments and were evaluated in terms of yield and weed control. Four different flaming dates were used--(1) Before or as the corn emerged, (2) when the corn was 2-4 inches high, (3) 8-10 inches high, and (4) 14-16 inches high. Eleven different combinations were used ranging from one to four applications.

An evaluation of the effect of rate of ground travel and burner pressure on the flame pattern was accomplished by measuring the temperature levels throughout the applied flame. This was done by the use of temperature sensitive indicators applied to screen wire panels located at several predetermined sites along the path of the burner.

The final phase of the study consisted of conducting a cost analysis of flame cultivation. Total cost as well as actual application costs were computed for two-, four- and six-row machines.

Results of the plots receiving the additional chemical applications indicated no reduction in yield from as many as three flamings. Although there was a temporary stunting of corn plants from cumulative flame applications, final plant heights showed no variation from non-flamed corn. Analysis of the data from the other plots showed a definite correlation between yield and the number of flame applications. The maximum average yield of 116.3 bushels per acre from three flamings was 23.8 bushels above the "check" treatments and 12.8 bushels per acre better than the "normal cultivation" plots.

The weed control experiment revealed the same correlation as yield--progressively improved weed control with additional flame applications. Control ranged from 20 per cent for one to 92 per cent with four flamings. Normal cultivation afforded 53 per cent control, about the same as two flamings.

Investigation of flame patterns indicated that the faster the ground speed the smaller the effective flame pattern. Increasing the burner pressure appears to increase the average temperature level within the pattern and can be used to off-set the effects of faster ground travel.

Total cost (including ownership costs) were computed to be $1.98, $1.47 and $1.27 per machine acre (per acre per application) for two-, four-, and six-row machines. Analysis of data on an annual-use basis indicated that the four-row machine was the most economical for the average farmer and would have an annual ownership cost of 40 cents per acre.

The conclusion of this study was that although further research is needed to verify and refine the findings of this initial work, flame cultivation does appear to be an effective and economically feasible method of controlling weeds in corn production in Kansas.