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Design and Construction of a Pneumatic-thermal Machine for Controlling Colorado Potato Beetle (*Leptinotarsa decemlineata)*

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Abstract: Because of the important role of the Colorado Potato Beetle (CPB) on the economy of potato production in most countries, a review of different methods of the insect control, especially mechanical approaches, has been done. Over the years, CPB has become resistant to most of the chemical pesticides and moreover, heavy application of these chemicals has lead to serious environmental problems. As a mechanical approach, a prototype pneumatic-thermal machine was designed and manufactured. This is a 4-row tractor mounted machine consisting of 4 centrifugal fans powered by the tractor PTO and 3 propane supplied burners. The test results of this machine showed that, with ground speed of 5 km h^{-1}, 1.5 ha of the field could be covered within 1 hour. In the air velocity of 29.33 m s^{-1}, the dislodged rate of CPB adults and larvae were estimated to be 95 and 85%, respectively. Propane consumption at 310 kPa pressure, when the ground speed was 5 km h^{-1}, was calculated to be 21 kg ha^{-1}. Overall, in countries where relatively cheaper fuel is available, this method of CPB control is, undoubtedly, both feasible and economical.

Key words: Pneumatic-thermal control, propane burner, centrifugal fan

INTRODUCTION

The Colorado potato beetle [Leptinotarsa decemlineata (Say)], originally native to Mexico, has been observed in North America in 1860 and later in Europe and Asia (Casagrande, 1999). The first case in Iran, was recorded in the province of Azerbaijan in 1981 and recently it has become the most important insect pest of potato crop and has been spread all over the country (Kazemi and Ardabili, 1999).

The adult insects overwinter in the soil and emerge early in the spring at 11°C and begin to feed young leaves of the crop. The feeding area in young plants was 120-1200 mm^2 per day (Tamaki *et al*., 1983). Adult mating occur continuously, within the plant growth period, which is about 3.5 months. Females lay up to 4000 eggs during their lifetime. The eggs are orange-yellow in color, can be found in clusters of about 20 on the underside of leaves. Eggs hatch in 4-9 days and larvae begin to feed immediately upon emergence. The larvae have 4 molts, which, depending on the temperature, takes a period of 2-4 weeks before entering the soil to pupate in a spherical cocoon. The new adults then emerge, depending on temperature, in 15-24 days and start to feed on leaves, immediately. Colorado potato beetle could have up to 4 generations. In cooler areas such as Azerbaijan it has only two generations.

The severe damage is usually caused by the first generation of adults and their larvae (Roush and Tingery, 1999). Moderate plant defoliation, less than 10%, does not affect yield significantly. However, higher populations of the insect usually cause severe damage especially in the beginning of flowering and results in plant death and significant yield reduction.

METHODS OF CONTROL

There are several means of dealing with CPB, including chemical, biological and mechanical approaches. The techniques are discussed briefly as follows:

Chemical control: Use of organic and inorganic pesticides for controlling CPB have been very common since 1950. It is recommended to spray the field for three times; first generation of larvae emergence, a week later and the second generation of larvae emergence. However, over the years, the insect has become resistant to most of the registered insecticides. Apparently, CPB is a typical example for insect resistance to chemical pesticides and the average effective period for a new pesticide is about 3.5 years (Hunt and Vernon, 2001). In order to overcome to this resistance, farmers often increase the chemical dosage or use stronger pesticides. However, heavy applications of chemical insecticides, can often lead to serious health and environmental problems.

Biological control: Biological control could be defined as a science of purposefully enhancing the activities of beneficial species to reduce the damaging activities of pest species. Biopesticides, depending on host, may include viruses, bacteria, fungi, predators, parasites and pheromones. These are living organisms and hence, their application may present problems that are completely different from chemical pesticides. It seems that the existing spray technologies for applying biopesticides are not 100% appropriate and on the other hand, farmers will face economic difficulties when purchasing specific equipment for application of every specific biopesticide. Furthermore, they are not sufficiently persistent and are relatively slow acting.

Colorado potato beetle has some natural enemies, such as a number of arthropod species. These predators attack eggs, larvae and adults providing some level of biological control of the beetle. For example, release of twospotted stinkbug-*Perillus bioculatus* at the rate of 3 per plant reduced beetle number by 60% (Biever and Chauvin, 1992). However, for a more effective control, higher number of predators per plant must be released which has been reported not economical (Ferro, 1994). Moreover, despite considerable research, the time and the rate of release, for more effective control remain unclear.

Physical controls: Physical approaches are other alternative means that have been developed in recent years. Among them, pneumatic, thermal and combined pneumatic-thermal controls have been investigated more than the other methods. Vacuuming insects out of plant canopy is not a new idea but because of the availability and the affectivity of chemical insecticides, interest was diminished for the use of pneumatic machines. However, chemical insecticides have revealed their disadvantages and since last decade pneumatic control has regained its importance and has been developing in recent years.

Weintraub designed and successfully tested a field scale blowing-vacuum machine (Weintraub, 2000). He developed the machine with two large fans installed in front of the tractor and powered by tractor hydraulic system. Airflow was directed to the plant row from both sides to dislodge insects and immediate vacuuming that covered the entire area between blowers resulted in an effective collection of dislodged insects. Plant damage caused by the tractor or blowing/vacuuming actions was reported to be not significant.

However, this technique does not always grant satisfying results. For example, dislodging eggs and larvae is always more difficult than adult insects (Schafer, 2003). In most cases weekly treatment is necessary, which, may cause soil compaction problems. It is also possible that some beneficial insects suffer from this technique and some fungal infection may also distribute in the whole field. However, for better treatment; firstly, the travel speed must be high enough; preventing pest from escaping the suction hood, secondly, pests sitting on the plant must fly before suction and finally, the suction hood must be extended in the direction of travel, in order to prolong the duration of pneumatic treatment.

It seems that, most of the existing problems related to the pneumatic treatment of CPB, are because of insufficient information on important engineering parameters. Airflow rate, air speed, travel speed and also the insect and plant behavior against these parameters must be studied broadly.

Thermal control: The concept of thermal control in agriculture is not new. It was mainly used on weeding of cotton and corn fields at the beginning of the 1900's then extended to many other crops such as; peanuts, soybeans, alfalfa, lettuce, onions, blueberry, strawberry and potatoes (Schwarzel, 1991; Trouilloud, 1993). However, because of the significant increase in fuel costs and also the attraction of pesticides due to their fast effects, the thermal method did not arouse interests in agricultural pest control and weeding but in petroleum producing countries, it has been investigated by several researchers, as an alternative approach. Thermal pest control is strongly dependent on timing. For example, in the case of CPB, flaming must be applied early in plant growth period when its height is not more than 15 cm (Lague *et al*., 1997). In this stage, although potato plant wilts temporarily, but it recovers in a short time and continues its natural growth. This early treatment results in a significant reduction in egg masses in young plants. However, heat treatment in older plants causes serious damage and results in a delay in plant growth and significant reduction in potato yield.

An extensive research program was conducted by a team of researchers from the University of Laval and Ministry of Agriculture in Quebec, Canada, to determine the technical and conomical feasibility of thermal top killing of potato plant and thermal weeding and CPB control early in the growing season of the crop (Gill *et al*., 1994). This research program resulted in valuable information such as thermal sensitivity of CPB and potato plants and time and number of controls, which is highly imperative for a successful thermal control of CPB.

Pneumatic-thermal control: In this method, which has been mainly experienced in North America, both pneumatic and thermal approaches are combined together (Lacasse *et al*., 1998; Lague *et al*., 1999). Thus, by applying airflow, the larvae and adult insects are dislodged from the plant and placed on the ground between crop rows, where they exposed to the flame. The fans and the burners are mounted on a common frame, which is usually attached to a tractor 3-point hitch. The related studies have indicated that the use of the combined pneumatic-thermal implement to control the population of CPB adults was as effective as chemical insecticides and can be an interesting alternative to chemical approaches. However, parameters such as, airflow velocities, airflow widths and travel speeds, are very effective on insect dislodging from the potato plant and must be carefully studied.

The combined pneumatic-thermal method has been tested only in North American countries, where it seems that the current fuel cost and land size are both too high for applying this method. On the contrary, in countries such as Iran, where the cheaper fuel can be provided and land size is usually small, this approach seems to be a more economical method for controlling CPB.

For further investigation of the effects of these parameters on the potato plant and CPB, a prototype field-scale pneumatic-thermal machine was designed and built in the Department of Agricultural Machinery of the University of Urmia (Tabibi, 2004).

MATERIALS AND METHODS

The prototype pneumatic-thermal machine to control CPB, was designed for the first time in Iran, in the Department of Agricultural Machinery, Urmia University, Urmia, Iran and constructed by Sadeed Niroo Company, Tabriz, Iran. The implement is fully mounted on the three-point hitch system of a row-crop farm tractor and powered by its PTO shaft. The computer software, 3d max, version 5.1, was used for machine modeling, where each part of the machine, its function and the relationship with the other parts was carefully considered. The whole machine was then designed according to these considerations (Fig. 1).

Mechanical Desktop 5.1, computer software, was also used to design a general view of the machine. This view includes the exact size of individual component and the whole machine with a proper scale. According to the design, which was performed in this software, the construction map of individual parts of the machine was fulfilled.

This machine consisted of three basic sections namely, airflow producing section, flame producing section and the main frame.

Fig. 1: Perspective view of the whole machine in 3d max. soft ware program

Fig. 2: Power train system from tractor PTO to the fans

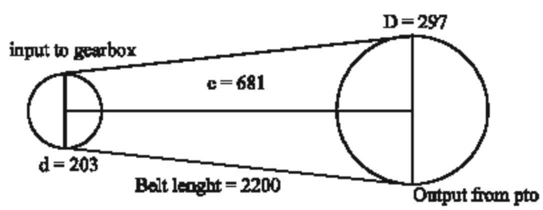

Fig. 3: The dimensions of belt-pulley system. D = large pulley diameter, d = small pulley diameter, C = distance between two pully centers (all in mm)

Airflow producing section: Four centrifugal double suction, forward-curved blade fans, model AT 10-10, manufactured by NICOTRA Co., in Italy were used to provide enough air flow with sufficient pressure to the plant rows. These fans received their required power by tractor PTO through a belt-pulley and then, by a gearbox system (Fig. 2). According to the company's catalogue, the power requirement for each fan, at the speed of 1970 rpm, was 2 kW and under these conditions, airflow velocity and pump capacity were estimated to be 11.2 m s^{-1} and 3850 m^3 h^{-1}, respectively. To provide the required speed and power to each fan, the power train was designed with the dimensions as shown in Fig. 3.

According to these dimensions, providing 540 rpm to the large pulley, the small pulley will revolve at 790 rpm and the ratio speed will then be; 1.463 A market available gearbox with a ratio of 2.5 was used, providing 1975 rpm to the fan impeller.

Centrifugal fans as compared to axial fans are less noisy and produce higher air discharge, which is more appropriate for this particular application. Airflow discharged from each fan outlet was directed through a flexible duct to provide horizontal airstreams across the potato plant rows. A mosquito screen was mounted on the opposite side of the plant row to stop CPBs in the air stream and direct them to ground surface between two rows. The air stream outlet was 420×85 mm and was equipped with separators to provide uniform airflow to the plant row. On the opposite side of the row, a horizontal grating of iron bars were mounted in front of screen to prevent the potato plants from excessive bending under the effect of airstreams.

Flame producing section: The dislodged CPB adults and larvae must be destroyed immediately before hiding themselves in the soil, with propane burners once they were deposited on the ground surface between rows. There were 3 gas burner units mounted on the main frame. Flame geometry, which affects temperature distribution in the flame, depends on the burner and nozzle design and also on the propane operating pressure (Lague *et al*., 1997). For example, flat vapor burners produce shorter and wider flames if equipped with short and wide jet nozzle and generate longer and narrower flame if fitted with narrow jet nozzle. In this particular application, a round vapor burner fitted with a narrow jet nozzle was used, which provided a long and narrow flame, appropriate for precise heat application for heat sensitive crops. Each burner was equipped with a small pilot flame to light the burner in the case of an accidental extinction. The flame height was 30 cm above the ground level and shields were provided to protect potato plants from heat. Furthermore, propane-operating pressure was adjusted with a pressure regulator and measured with a pressure gauge, which was mounted on the propane common line from tanks to the burners. Two 35 L Liquefied Petroleum Gas (LPG) tanks were used to supply propane to the burners.

Propane consumption in relation with burner type and gas operating pressure was calculated by using the following empirical equations (Lague *et al*., 1997):

$q = a \times p$. where, q is propane consumption, kg/h-burner; p is gas operating pressure, kPa; a is constant function of burner type, kg/h-burner-kPa. For round vapor burner fitted with a narrow jet nozzle used in this experiment, a equals 0.025. Propane consumption per hectare can then be determined using the following equation:

$Q = 10\ q/ve$ where, Q is propane consumption of a given treatment, kg/ha; v is machine forward speed, km/h, e is burner spacing (m/burner) multiplied by number of burners in the machine (machine width), which in this experiment equals to 3. The coefficient 10 is a conversion factor; (km-m ha^{-1}).

Fig. 4: General view of the combined pneumatic-thermal machine

Main frame: The main frame consisted of a 10×10 cm, square industrial profile with a length of 340 cm. Four fan units, 3 burners, power train system, mosquito screens and plant supporting iron bars were all mounted on the main frame with their proper sub-frames. The main frame was equipped with three-point hitch system to be mounted to a tractor three-point hitch. The machine was allowed to slide over the ground surface by 4 small wheels in order to follow surface irregularities of the field (Fig. 4).

Details of the design and construction of the machine is available (Tabibi, 2004).

RESULTS

There were two main aims for the prototype machine; first, to produce effective air stream in order to dislodge the CPB from plant canopy and second, to destroy the dislodged insects on the ground between rows by flaming.

The pneumatic-thermal machine was tested in the field both in steady state and on-the-go conditions (Fig. 5). Overall, the machine operated satisfactorily. At the 540 rpm of tractor PTO, the maximum air velocity at the air duct outlet was measured to be 29.33 m s^{-1} and according to the air duct outlet dimension (420×85 mm), the fan capacity was calculated to be 3769 $m^3 h^{-1}$. In the measured air velocity, the dislodged rate of adults and

Fig. 5: Operation of the combined pneumatic-thermal machine in the field

Fig. 6: Three separators installed in the air stream duct separating it into 4 sections

larvae were estimated to be 95 and 85%, respectively. Some small larvae and adults, especially those were located at higher part of plants survived. This suggests that the air velocity must be increased around to 50 m s^{-1} (Lacasse *et al*., 1998a; Lague *et al*., 1999).

However, the air velocity measured at the top of the outlet, as compared to the bottom of it, was significantly low. The reason being that, air stream tended to flow straight down the duct prior to exit. To prevent this undesired action, three sheet separators were welded inside the sheet duct in order to divide the incoming air stream between 4 sections to provide more uniform airflow from the outlet (Fig. 6).

To evaluate the power train performance, the total efficiency for the belt-pulley system and gearbox was calculated. At 540 rpm of tractor PTO, the speeds of two pulleys were 540 and 783 rpm. Accordingly, for the input and output shaft of gearbox it appeared to be 783 and 1964 rpm, respectively. The calculated ratio for the belt-pulley system and gearbox then were 1.45 and 2.5, respectively. Comparing these ratios with those obtained from dimensions (1.46 for pulleys; 2.5 for gearbox), the

Table 1: The measured and calculated parameters for power train.

	Large pulley	Small pulley	Gearbox input	Gearbox output
Measured data	540	783	783	1964
Speed ratio		1.45×2.5 = 3.63		
Calculated data	540	790	790	1975
Speed ratio		1.46×2.5 = 3.65		
Total speed Efficiency		0.99		

total efficiency for power train was calculated to be 0.99, which indicates excellent performance of the system.

Table 1 shows the measured and calculated data for the power train speed efficiency.

The manufactured machine was tested to investigate the quality of burners operation. The test was carried out on a 100 m track at a windy weather condition. During this operation, tractor travel speed was 5 km h^{-1} and the gas operating pressure was set at 310 kPa. This operating pressure provided a conical flame with proper distribution to cover a larger area on the ground.

The propane consumption of the machine at these settings was calculated to be 21 kg ha^{-1}. The burner spacing in this machine was 0.75 m. The consumed propane was also measured under these conditions by weighing the fuel tanks before and after test, which was slightly lower than the calculated value. The reason being that, the constant "a" in the empirical equation (G = p*a*10/v*e) probably did not match completely with the type of the burner and its jet nozzle installed in this machine. It is also worthwhile to mention that, the propane operating pressure was gradually diminished as the tank propane was being used and it was almost impossible to keep this pressure constant, particularly when the two tanks were less than half full, by adjusting the existing regulators.

However, the cost of this amount of propane in Iran is about 1.5 US dollars whereas, 1.5 liters of chemical pesticides for one hectare would cost 8 US dollars. The operation costs for both methods appeared to be almost the same.

DISCUSSION

Pneumatic-thermal control of CPB is certainly feasible and it has already been experienced in Canada (Lague *et al.*, 1999). However, this approach can be limited in some countries where the fuel cost and land size is very high. On the contrary, in countries with remarkable fuel resources and small field sizes, such as Iran, it seems that, the method is undoubtedly both practical and economical.

The pneumatic-thermal control machine reported in this paper will be ready for operation in an experimental field in near future, where the method will be compared with conventional chemical approaches. However, it is highly recommended that the effect of some important engineering parameters such as; machine forward speed, airflow velocity, the shape of airflow duct and air outlet and stream direction be further investigated.

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REFERENCES

Biever, K.D. and R.L. Chauvin, 1992. Suppression of the Colorado potato beetle (Coleoptera: Chrysomelidae) with augmentative release of predaceous stinkbugs (Hemiptera: pentatomidae). J. Econ. Entomol., 85: 720-726.

Casagrande, R.A., 1999. Colorado potato beetle. In: www.rui.edu/ce/factsheets/sheets/colpotbeetle.html.

Ferro, D.N., 1994. Biological Control of the Colorado Potato Beetle. In: Zehnder, G.E., M. L. Powelson, R.K. Jansson and K.V. Raman, (Eds.). Advances in Potato Pest Biology and Management. Aps Press, St. Paul, pp: 357-375.

Gill, J., C. Lague, N. Lehoux and R.M. Duchesne, 1994. Use of propane flamers in potato production. Joint project of the University of Laval and Ministry of Agriculture, Fisheries and Food. Quebec, Canada.

Hunt, D.W. and R.S. Vernon, 2001. Portable trench barrier for protecting edges of tomato fields from Colorado potato beetle. J. Econ. Entomol., 94: 204-207.

Kazemi, M.H. and J. Ardabili, 1999. Evaluation of bio-ecology condition of Colorado potato beetle (*Leptinolarsa decemlineata(Say)*], from 1984 to 1990 in Ardabil territory. J. Agric. Sci. Tabriz Uni. Publ., 9: 41-53.

Lacasse, B., C. Lague, M. Khelifi and P.M. Roy, 1998. Field evaluation of pneumatic control of Colorado potato beetle Can. Agric. Eng., 40: 273-280.

Lague, C., J. Gill, N. Lehoux and G. Peloquin, 1997. Engineering performances of propane flamers used for weed, insect pest and plant disease control. Appied Eng. Agric., 13: 7-16.

Lague, C., M. Khelifi, J. Gill and B. Lacasse, 1999. Pneumatic and thermal control of Colorado potato beetle. Can. Agric. Eng., 41: 53-57.

Roush, R.T. and W.K. Tingery, 1999. Evaluation and management of resistance in the Colorado potato beetle. In: Proceedings of the symposium resistance 91: Achievements and developments in combing pesticide. Eds, Denhom, I., A.L. Devonshire and B.W. Hollomon).

Schafer, W., 2003. Technique for Pneumatic Pest Control. MTT Agricultural Engineering Research. Vihti, Finland. Poster presented at NJF's 22nd Congress. Nordic Agriculture in Global Perspective, Turku Finland.

Schwarzel, R., 1991. Thermal drying system on potato plant cultivation. Revue suisse d. Agric., 23: 133-135.

Tabibi, Z., 2004. Design and construction of a pneumatic thermal machine for controlling Colorado Potato Beetle. Graduate thesis, Agricultural Machinery Department, Agricultural Faculty, Urmia University, Urmia, Iran.

Tamaki, G., R.L. Chauvin and A.L. Burditt, 1983. Laboratory evaluation of doryphorophaga doryphorae (Dip. Thachinidea) a parasite of the Colorado potato beetle (Col. Chrysomelidea). J. Environ. Entomol., 12: 390-392.

Trouilloud, M., 1993. Thermal Control. In: Non Chemical Weed Control, Proc. of the 4th IFOAM International Conference, Thomas, J.M., (Ed.), Quetigny, France Enita, 173-177.

Weintraub, P.G., 2000. Pest Control by Vacuum Removal. A Research Report. Gilat Research Center. Available at: www.molcho.org.il.