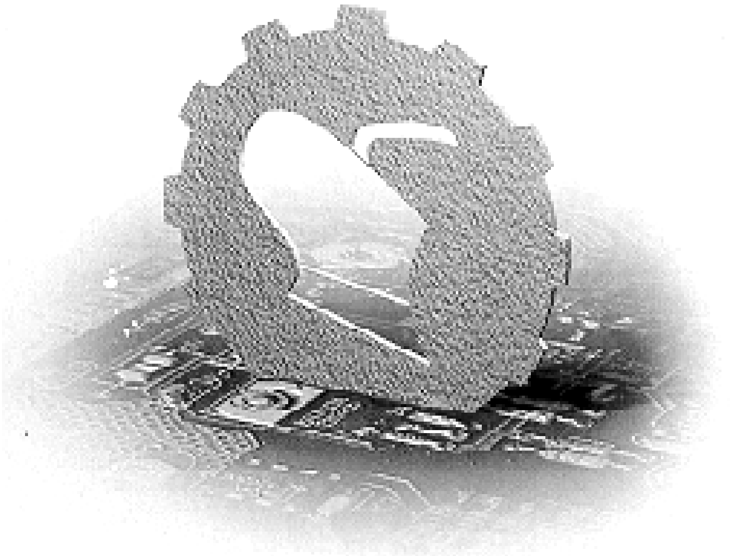
Print ISSN 0554-5587
Online ISSN 2406-1123
UDK 631 (059)

ПОЉОПРИВРЕДНА ТЕХНИКА

AGRICULTURAL ENGINEERING

НАУЧНИ ЧАСОПИС
SCIENTIFIC JOURNAL



УНИВЕРЗИТЕТ У БЕОГРАДУ, ПОЉОПРИВРЕДНИ ФАКУЛТЕТ,
ИНСТИТУТ ЗА ПОЉОПРИВРЕДНУ ТЕХНИКУ
UNIVERSITY OF BELGRADE, FACULTY OF AGRICULTURE,
INSTITUTE OF AGRICULTURAL ENGINEERING

Година XL, Број 1, 2015.
Year XL, No. 1, 2015.

Издавач *(Publisher)*
Универзитет у Београду, Пољопривредни факултет, Институт за пољопривредну технику, Београд-Земун
University of Belgrade, Faculty of Agriculture, Institute of Agricultural Engineering, Belgrade-Zemun

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11080 Београд-Земун, Немањина 6, тел. (011)2194-606, 2199-621, факс: 3163-317, 2193-659, e-mail: gogi@agrif.bg.ac.rs, жиро рачун: 840-1872666-79.

11080 Belgrade-Zemun, str. Nemanjina No. 6, Tel. 2194-606, 2199-621, fax: 3163-317, 2193-659, e-mail: gogi@agrif.bg.ac.rs , Account: 840-1872666-79

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"Академска издања" – Земун
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Тираж *(Circulation)*

350 примерака

Pretplata za 2016. godinu iznosi 2000 dinara za institucije, 500 dinara za pojedince i 100 dinara za studente po svakom broju časopisa.

Радови објављени у овом часопису индексирани су у базама *(Abstracting and Indexing)*:

AGRIS i SCIndeks

Издавање часописа помогло *(Publication supported by)*

Министарство просвете и науке Републике Србије

Na osnovu mišljenja Ministarstva za nauku i tehnologiju Republike Srbije po rešenju br. 413-00-606/96-01 od 24. 12. 1996. godine, časopis POLJOPRIVREDNA TEHNIKA je oslobođen plaćanja poreza na promet robe na malo.

S A D R Ž A J

C O N T E N T S

Univerzitet u Beogradu
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POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 1 – 9

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No. 1, 2015.
pp: 1 – 9

UDK: 631.372

Originalni naučni rad
Original scientific paper

REAL TIME FUZZY LOGIC SYSTEM FOR CONTINUOUS CONTROL SOLENOID VALVE IN THE PROCESS OF APPLYING THE PLANT PROTECTION PRODUCT

Peter Berk[*1], Denis Stajnko[1], Miran Lakota[1], Aleš Belšak[2]

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Abstract: In the area of spray technique complex dynamic systems are very often faced with nonlinear or time-variable behavior. Therefore, such a process is difficult to determine in the model, since it can be inaccurate and therefore useless. So we decided in our application for real time fuzzy logic system, by which we can proportional controlled a process of applying plant protection product (PPP). The real time fuzzy logic system was realized with the HP laptop 6830s Compaque NA779ES, software Matlab/Simulink R2013b, fuzzy logic tool FIS (Fuzzy Inference System), proportional solenoid valve, ultrasonic measurement system and Lechler nozzle. With the help of fuzzy logic system for control consumption amounts process of PPP was found, that we can reduce the quantitative use of PPP, through the solenoid proportional control valve in the range of 0 to 100 %, depending on the intensity of the reflected signal from canopy of the tree.

Keywords: *fuzzy logic system, plant protection product, control, solenoid valve*

INTRODUCTION

A recent wave of commercial fuzzy products, most of them from Japan, has popularized fuzzy logic. In 1980 the contract firm of F. L. Smith and Company in Copenhagen first used a fuzzy system to oversee the operation of a cement kiln. In 1988 Hitachi turned over control of a subway in Sendai, Japan, to a fuzzy system, [1].

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Since then, Japanese companies have used fuzzy logic to direct hundreds of household appliances and electronics products. The Ministry of International Trade and Industry estimates that in 1992, Japan produced about 2 billion worth of fuzzy products. U.S. and European companies still lag far behind. Applications for fuzzy logic extend beyond control systems. Recent theorems show that in principle fuzzy logic can be used to model any continuous system, be it based in engineering or physics or biology or economics or agriculture. Investigators in many fields may find that fuzzy, commonsense models are more useful or accurate than are standard mathematical ones.

Controlling these problematic processes take place mainly on the basis of human experience and its direct intervention in the process, [4]. Fuzzy controllers are able to summarize human knowledge of the system and introduce them to the laws of control. This is possible by solving management problems, without creating a precise model required by classical control engineering. This is the reason that the use of fuzzy logic took hold mainly in control engineering. The use of fuzzy logic in industrial applications is increasing in the recent years. Japanese industry has launched an aggressive marketing of fuzzy ideas in the form of the first commercial outputs [1].

Industrial Engineering (IE) is concerned with the design, improvement, and installation of integrated systems of people, material, equipment, and energy. Industrial engineers face many problems with incomplete and vague information in these systems since the characteristics of these problems often require this kind of information. Fuzzy sets approaches are usually most appropriate when human evaluations and the modeling of human knowledge are needed. IE brings a significant number of applications of fuzzy set theory. The major application areas are Control and Reliability, Engineering Economics and Investment Analysis, Group and Multi-criteria Decision-making, Human Factors Engineering and Ergonomics, Manufacturing Systems and Technology Management, Optimization Techniques, Statistical Decision-making, [2] and in the future process in Agriculture.

MATERIALS AND METHODS

The Matlab R2013b and fuzzy logic toolkit FIS adds sophisticated control algorithms to our instrumentation software development system. By combining the control functions in toolkit with the math and logic functions in the Matlab development environment, we can quickly develop programs for automated control, [5]. Integrate these control tools with NI data acquisition hardware to easily create control systems.

Be aware of the need to that control quantitative dose PPP very dynamic process. Therefore, it is necessary to draw attention to changes that occur outdoors or. field, where various forms of tree crown and barriers between lines of canopy trees can lead to wide ranges of tractor speed, pulling behind a sprayer.

Therefore, in practice, more frequently use applications that is the most adaptable to the current situation on the ground. That, we can define quality process control application of PPP, at selected canopy trees, we are in the process model integrated the fuzzy logic system, [6]. The entire structure of the application process of PPP shown in Fig. 1. Structure of the real time process of application PPP, we have done with the help of software tools Matlab / Simulink and hardware components.

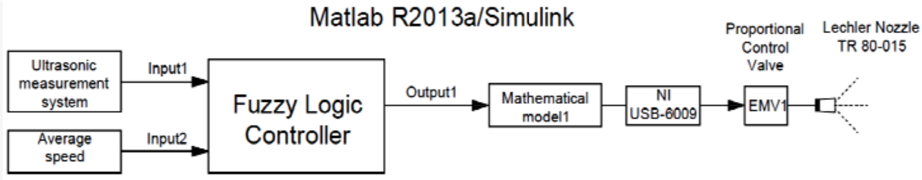

Figure 1. Structure of the real time process of application PPP

Hardware

The hardware of the process for the application of PPP consists of:

- A hardware control cycle consists of the HP Compaq 6830s. A HP 6830s Laptop has a 3 GB DDR2 800 Mhz memory, expandable to 8 GB. Hard Drive has capacity of 320 GB, supports SMART SATA bus communicates and operates plants in 5400 in a minute,
- Posiflow Proportional Solenoid Valves, ASCO procuder, type 2/2 8202 with a flow rates adjustable between 0 % and 100 % of rating and flow rate can also be regulated by a range of electrical inputs (sensors, transmitters, PLC, etc.),
- Lechler nozzle type TR 80-015,
- NI USB-6009 card and
- Ultrasonic measurement system, [3].

Software Matlab/Simulink R2013a

Matlab is a software package designed for numerical calculations, such as arithmetic operations of vectors, differential equations and presentation of results. For such extensive use the Matlab has available libraries through, which more knowledge about the regulation (continuous, discrete, fuzzy), designing of filters, XPC Target System can be reached, [7]. Due to the ease of use Matlab to become a tool, they have become widely used. It is suitable for teaching, research and solve practical problems. MATLAB language has rich data structures and also object-oriented. Because Matlab interprets own files, the loss of much valuable time, but it is possible to code m-files to translate and thus significantly speed up the implementation of the program. On the other hand, bottlenecks program, who spend the most time, encoded in any other programming language, such as C. Matlab code can be translated into mex-file, it know how to use Matlab as its own m file, only that translated performed much faster. Matlab has some distinctive advantages:

- quickly and easily writing programs,
- available to receive high-quality tools for visualization,
- program running on multiple operating systems and
- special offers software tools for working with fuzzy logic systems (FIS; fuzzy inference system), which may include the acquisition and processing of data from external devices by using the tools DAQ (Data Acquisition Toolbox).

As a basic tool for the design of fuzzy logic system, we used Matlab Simulink subsystem, through which you can expand the area of nonlinear dynamical simulations, time-dependent processes.

Simulink enables the development of functional units of fuzzy systems in a simple way, with the known structures of different process models and control loops. Such are created possibilities for the combination of fuzzy logic and conventional techniques and their simulation testing. The simple and open system architecture Matlab program it is possible to realize all the usual procedures and a Simulink tool also offers the possibility of optional finishing and extension.

Fuzzy logic tool FIS

Three partial processes of fuzzy logical system we planned with the help of fuzzy logical tool FIS, which is implemented in the Matlab program.

For the construction, editing, and monitoring fuzzy logic system, exists in the FIS five basic components. These are:

- editor for the determination of fuzzy inference system FIS ("FIS Editor"),
- membership function editor,
- rule editor,
- rule viewer and
- surface viewer.

In the system of the FIS are dynamically integrates and interconnected all core components, [8]. Any changes that have an impact on individual functional components, such as various settings membership functions of input and output variables, can be set in the fuzzy logic system FIS. In the FIS, we set a different number of input and output variables for our fuzzy logic system, with which was continuously controlled the synthesis process of application of PPP. In the editor membership functions was identify their triangular, trapezoidal and rectangular shape. Editor of the rules we used to edit the list of rules, through which was determined the response of fuzzy logic system. Rule viewer represent Matlabs technical tool, that shows fuzzy diagrams of membership functions in the field of operating point. The rule viewer is used for the diagnosis of active rules and provides, how different forms of membership functions repercussions on the final calculation of the output value linguistic variable of fuzzy logic system. With the help of the surface viewer the characteristic fields can show the output values of the variables of the fuzzy system, which depend on different sets of input values of the variables of the fuzzy system.

Modeling real time application of PPP with fuzzy logical system

Fuzzy logic system for continuous control of the proportional solenoid valve, which was made by using Simulink subsystem, Matlab R2013a and software tools FIS, can be considered as a system with non-linear static characteristic in the application process of PPP. Therefore, we are in the process of application of PPP include fuzzy logic system, where form of non-linearity of the fuzzy logic system depends on the rule base and membership functions of input and output linguistic variables depends on the rule base and membership functions of input and output linguistic variables tagged with: Sensor, $\bar{v}$ and El-mag. Optimization of fuzzy system, we started with the process of fuzzification two input and one output linguistic variables. Input and output linguistic variable fuzzy controllers we are define each of them with a reference value in the interval [0, 600]. Reference values for each input linguistic variables of the system represented the normalized intensity values reflection of the ultrasound signal from the tree canopy, which was captured via the ultrasonic sensor, [3].

The input linguistic variable we are defined with a reference value in the interval [0, 1] and represent a traveling speed of sprayer. Reference values for each output linguistic variables of the fuzzy system represented values, with which we can continuously controlled solenoid valves in the range from 0 % to 100 %. Input and output linguistic variables was by using tools FIS, described by three membership functions trapezoidal shape, shown in Figs. 2 and 3, whereas, in this case trapezoidal membership functions shown as the most suitable. Membership function was presented with linguistic values described in Tab. 1.

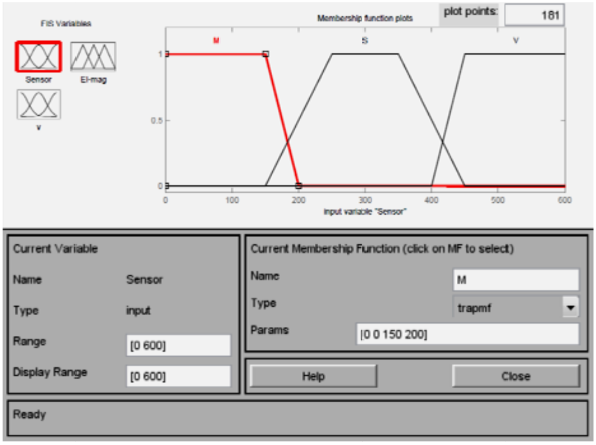

Figure 2. Membership functions of linguistic variable Sensor

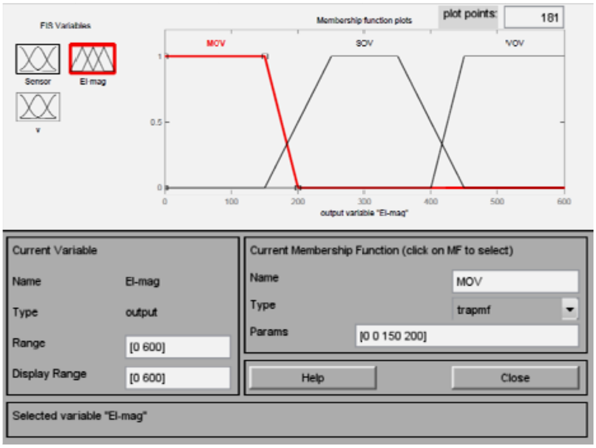

Figure 3. Membership functions of linguistic variable El-mag

After completing the process of fuzzification two input and one output linguistic variables was continue with the procedure inference, which represents the decision-making process. The procedure was carried out, that we wrote a multitude of rules in the form of Tab. 2, for the control of the proportional solenoid valve.

Table 1. Description of the degree of linguistic value membership functions

Linguistic value (label in the FIS)*	*The rate of linguistic values (describe in words)*
M	*Low*
S	*Middle*
V	*Lot*
MOV	*A little open valve*
SOV	*Medium open valve*
VOV	*Lots of open valve*

**The rate of linguistic values ranged between 0 and 1.*

The total number N of possible rules for the fuzzy logic system was defined by the formula:

$$N = p^m = 3^2 = 9 \quad (1)$$

Where:
p [-] - number of levels linguistic values for each input linguistic variable,
m [-] - number of input linguistic variables.

Table 2. Rules for controlling solenoid valve

The rules for controlling solenoid valve			
Rule	*Input 1 (Sensor)*	*Input 2 ($\bar{v}$)*	*Output (El-mag)*
1	*M*	*M*	*MOV*
2	*M*	*S*	*MOV*
3	*M*	*V*	*MOV*
4	*S*	*M*	*MOV*
5	*S*	*S*	*SOV*
6	*S*	*V*	*SOV*
7	*V*	*M*	*SOV*
8	*V*	*S*	*VOV*
9	*V*	*V*	*VOV*

Importance of levels membership functions of each linguistic variable shows Tab. 1. Language description of the fuzzy logic system, we have made with the form "IF THEN" and the total number of rules is 9.

The rules was added to the rules editor in the fuzzy logical tools FIS. In the language of control techniques we have assumed: if the input value of the ultrasound sensor, [3], small and average speed sprayer a small, then the solenoid valves a little open, depending on the working area of a proportional solenoid valve. After the establishment of rules for controlling the solenoid valves we have created inference, which represented the set of fuzzy output, using the operator inference. In the fuzzy logic system was used Mamdani operator inference, with whom we have created a set of membership functions of the rules, relating to the output parameter, [1]. Then followed a procedure focus, where we have chosen gravity method, which, in practice, the most frequently used and contribute best results. The method allows the calculation of the sharp in control technology useful variables, by which can be controlled executive actuators, such as proportional solenoid valves. After of three procedures, was completed the planning of fuzzy logic system. Optimization of fuzzy logic system was carried out, that we are taking configure stability, robustness, quality of the system and behavior change in the value of the linguistic membership functions and their forms and rules. Then, we have included the design of fuzzy logic system into the final mathematical model. In the mathematical model of the system we have take into account its dynamic properties.

With the use of the subsystem Simulink we have compiled a model of fuzzy logic system by showing in Fig. 4. In the planning system we have take advantage of simulation tools such as Matlab and its associated subsystems.

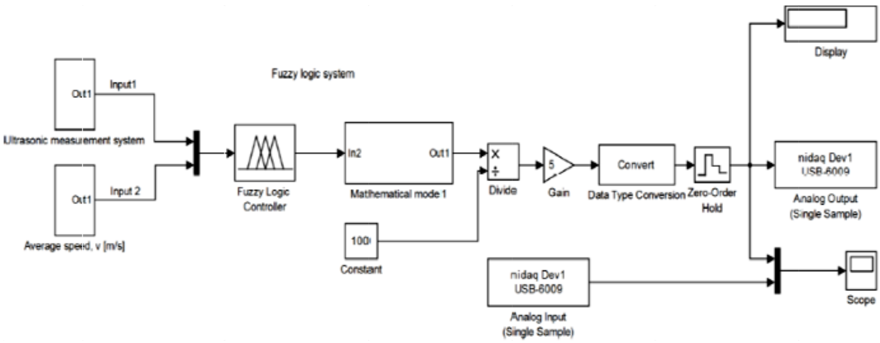

Figure 4. Fuzzy logic system design for process of application of PPP

RESULTS AND DISCUSSION

Figs. 5 and 6 show the different types of ramp output signals with which can continuously controlled proportional solenoid valve in the range of 0 % to 100 % and control voltage from data acquisition card NI USB-6009, in the range of 0 V to 5 V.

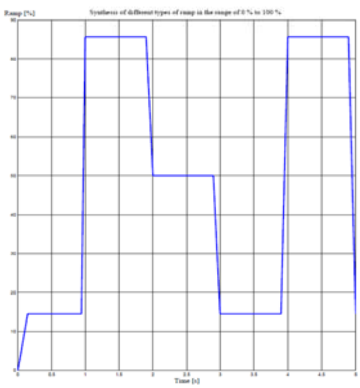

Figure 5. Different types of ramp in the range of 0 % to 100 %

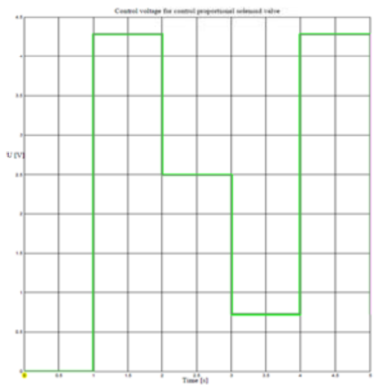

Figure 6. Real time output control voltage in the range of 0 V to 5 V

The figures clearly show that in the case of low numerical values, which represented the intensity of the reflected signal from the tree canopy and which bring in first input of the fuzzy logic system is obtained at the output of the fuzzy logic system openness proportional solenoid valve in the range of 15 %. In the case of greater numerical values to the input fuzzy logic system, is obtained at the output of fuzzy logic system the openness of the proportional solenoid valve in the range 85 % and at middle numerical values to the input fuzzy logic system, is obtained at the output of fuzzy logic system the openness of the proportional solenoid valve in the range 50 %. On the second input of the fuzzy logic system we brought the average value of the travel speed of the sprayer, which are 1 $m \cdot s^{-1}$.

CONCLUSIONS

The research results confirm that could be used model of fuzzy logic system in real process of automated application of PPP in selected parts of the tree canopy, where the method of constant-direct application usually does not produce satisfactory results. We found that the fuzzy logic system allows the user to use their own knowledge of the problem and transferred to the appropriate system environment, which is close to the human way of thinking.

Since this is a more complex task than simply inserting control parameters, we used the special user interface (FIS) for planning fuzzy logic applications. Fuzzy logic system in the application control process of the proportional solenoid valve proved to be a very good choice, because the process of planning a fuzzy logic system quite simple and appropriate for engineering practice. The results showed that it is possible with the help of fuzzy logic system reduce the use of PPP, as the system adjusts the density of leaf area, travel speed of sprayer and according to the input numerical value of the density of leaf area, and a travel speed if necessary, the fuzzy logic system controls the flow of PPP through the proportional solenoid valve.

So far, we have made the real time process of volume application plant protection product implemented with a fuzzy logic system, for one proportional solenoid valve. In the future we want to do real design control process which will be supported by the control and more actuator units, where we controlling in the real time more proportional solenoid valve.

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MEKANI LOGIČKI SISTEM ZA KONTINUIRANU KONTROLU MAGNETNOG VENTILA U REALNOM VREMENU, U PROCESU OBLAGANJA ZA ZAŠTITU BILJA

Peter Berk[1], Denis Stajnko[1], Miran Lakota[1], Aleš Belšak[2]

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Sažetak: U oblasti primene tehnike za zaštitu bilja složenim dinamičkim sistemima istraživači se suočavaju sa nelinearnim i vremenski promenljivim ponašanjem procesa. Za takav proces je u praksi veoma teško odrediti model, pa su zato neki modeli netačni i beskorisni u praksi. Zato smo se odlučili za aplikaciju koja će raditi na principu realnog mekanog logičkog sistema, kojim možemo kontinuirano upravljati magnetnim ventilom u primeni sredstava za zaštitu bilja. Mekani logički sistem realizovan je pomoću hardver alata HP laptop 6830s Compaque NA779ES, proporcionalnog magnetnog ventila, ultrazvučnog mernog sistema, LECHLER mlaznice i softver alata Matlab/Simulink R2013b, mekanog logičkog alata FIS (Fuzzy Inference System). Otkrili smo, da korišćenjem mekanog logičkog sistema kontinuirano kontrolišemo upotrebu sredstava za zaštitu bilja, preko proporcionalnog magnetnog ventila u opsegu od 0 % do 100%, u odnosu na ultrazvučni signal koji se oduzima od krune drveta.

Ključne reči: *mekani logički sistem, zaštita bilja, kontrola, magnetni ventil*

Prijavljen: *Submitted*:	12.09.2014.
Ispravljen: *Revised*:	
Prihvaćen: *Accepted*:	08.03.2015.

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
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Godina XL
Broj 1, 2015.
Strane: 11 – 18

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Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No.1, 2015.
pp: 11 – 18

UDK: 631.354.2

Originalni naučni rad
Original scientific paper

IMPACT OF TRITICALE MASS YIELD ON HARVEST SPEED

Vojislav Simonović*, Dragan Marković, Nikola Mladenović, Ivana Marković, Žarko Čebela

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Abstract: This paper analyzes the effect of triticale yield on the speed of the combine during harvest. Monitoring system for the site-specific yield is mounted to harvester with 6 meters wide header. After harvest, the yield is divided into three groups, as well as small, medium and large yield, and then using the Kruskal-Wallis H test analyzed the rate of speed for each group along the plot. It was found for analyzed field that the speeds different and based on the average value ranges group concluded that the speed decreases with increasing yield, and access the subsequent analysis of the differences between the groups using the Mann-Whitney U test. The speed of the combine during harvest triticale in the analyzed plot differ significantly when comparing the three groups, and small and medium impact to Cohen's criteria based on effect size.

Key words: *trItical, speed, yield, Kruskal-Wallis H test, Mann-Whitney U test*

INTRODUCTION

In order to investigate the influence of triticale yield on the speed of the combine during harvest will be used Kruskal-Wallis H test. This test is used to compare the results of a continuous variable with three or more groups. In other words, this test tests the null hypothesis that k independent samples drawn from the same population or populations with the same median. The only assumption of this nonparametric test are that the observed variables have a continuous distribution and that measured at least at the ordinal measurement scale. Research question, therefore, as follows, is there a

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The results are part of the Ministry of Education and Science program and research, entitled „Research and development of equipment and systems for industrial production, storage and processing of fruits and vegetables", No. TR 35043.

difference in the speed of the combine, depending on the yield into three groups (range)? Sharing the yield in the three groups, and bearing in mind the most direct connection speeds harvest and productivity, classify land at low, middle and highly fertile, and harvesting at low, middle and highly productive. By default, this research also includes the operator's subjective habits that directly affects the speed of the combine. This factor, however, was reduced to a minimum, because the combine operated by an experienced operator. Gradual and sudden speed changes affect the accuracy of yield measurements. Arslan and Colvin [1] showed that average error rates at a constant speed were 3 %, but varying speed between 8 and 11 km/h increased the average error to 5.2 %. When combine speed varied gradually, depending on yield variation, the measurement error almost doubled. Larger errors are observed when ground speed changes abruptly [2]. Many studies [3] [4] [5] have found that non-normal yield distributions are due to a high proportion of low yield measurements. The analyzed field in this paper have also non-normal yield distributions.

MATERIAL AND METHODS

Yield monitoring in combine harvesters is a cornerstone of precision agriculture. It relies on measurement of the grain flow through the harvesting equipment. Typical mechanisms that have been implemented to monitor grain flow through a combine can be grouped into volumetric flow sensors, mass flow sensors, and indirect measurement devices. Among them, impact-type mass flow sensors are widely used in many state-of-the-art yield monitors [6]. They consist of an impact plate and a force transducer that converts the net time-averaged impact force into a voltage signal. This type of structure is so simple that impact-type sensors can be easily mounted on combine harvesters and risk of causing an obstruction of the normal threshing process, even when the sensors are damaged, is minimized [7].

Combine harvester used in this investigation was fitted with a header, 6m wide. A grain mass flow sensor positioned on the top of the clean grain auger, Fig. 1a, and a grain moisture sensor positioned on the middle of the clean grain auger, Fig. 1b. The sensor measures the impact force with which the grain expelled from the paddle elevator strikes against the impact plate. Using this force, as well as known header width, speed of motion and grain auger speed, the moist grain mass yield is calculated. The effect of combine vibrations was eliminated by previous sensor calibration.

Implemented sensors on the respective positions of the basis for the collection of parameters of interest in a combine harvester. Measured values observed in real time can contribute to the optimal operation, and their storage and analysis can make a significant contribution in making decisions related to future processes [8]. The system for measuring rapeseed yield is adjusted to consecutively register yield at 2-second intervals. This was a constant measuring time interval. The only parameter that changed was the distance travelled during that time, which was dependent of the combine harvester speed of motion. It was also registered for each 2-second time interval. During this interval, a number of grain contingents carried by the grain auger paddles were discarded and directed to the impact plate of the mass flow sensor.

Mass flow monitoring started 10 seconds after the adapter with a cutter-bar was lowered for working position, and finished 10 seconds on lifting the cutter-bar.

Practically, there was a time shift for mass flow monitoring, consequently the yield, actually amounting to 10 seconds and representing transport time delay, i.e. the time needed for crop grain to travel through combine technological devices from the time moment of cutting to the time moment of grain striking against the impact plate of the mass flow sensor.

a b

Figure 1. a. Gap between elevator and auger for clear grain and impact plate of mass flow sensor with modul (view from grain tank), b. grain moisture sensor

Various factors such as combine separator design and settings and monitoring systems can affect the data gathering process so that the time shift should be adjusted. Without this adjustment, the grain flow and moisture values cannot be properly coordinated with location and area information to deliver data that accurately represent that location [9].

RESULTS AND DISCUSSION

The influence of the mass yield of dry grain triticale on the speed of the combine was investigated on the farm PKB within the field 40 Padinska Skela. In order to research conducted procedures as required by the Kruskal-Wallis H test was performed categorization of continuous variables by weight of dry grain yield for this plot, so it is divided into the following groups (bands):

- small yield ($\leq 4.490\ t \cdot ha^{-1}$),
- middle yield ($4.491 - 4.970\ t \cdot ha^{-1}$),
- large yield ($\geq 4.97\ t \cdot ha^{-1}$).

Based on the shown distribution, it can be seen that the number of samples within each group each (Tab. 1). Site yield of dry grain triticale on this field per display distribution, is given in Fig. 2 Such groupings yield of dry grain can be defined organizational zone explored part of the plot. This view is particularly characterized by long passes of 2.3 km. Harvesting the plot is done three to five combines, but only one was equipped with tracking devices yield. The results of analysis using appropriate software procedures in SPSS Statistic 21 are given in Tabs 1 and 2.

Figure 2. Representation of site-specific dry grain yield, tons per hectare

Table 1. Average rang of speed for binned mass yield dry grain

	Mass yield dry grain (Binned)	N	Mean Rank	Median
Speed	<= 4.490	2475	4394.31	5.620
	4.491 - 4.970	2445	3912.87	5.480
	4.971+	2456	2753.87	5.220
	Total	7376		5.430

Table 2. Results of Kruskal-Wallis H test for harvest speed

Grouping Variable: Mass yield (Dry) (Binned)	Speed
Chi-Square	772.223
df	2
Asymp. Sig.	.000

Kruskal-Wallis H test revealed a statistically significant difference in the speed of the combine in parts of plots belonging to different groups yield (group 1, *N*=2475: do $4.49\ t \cdot ha^{-1}$); group 2, *N*=2445: $4.491 - 4.970\ t \cdot ha^{-1}$); group 3, *N*=2456: > $4.97 t \cdot ha^{-1}$)), χ^2(2, N=7376)=772.223, p=0.000. Low yields group is characterized by higher median ($M_d = 5.62$) than the other two groups yields, whose median is $M_d = 5.48$ for a group of middle yield and $M_d = 5.22$ for the group of the largest yields. In the above results, the level of significance is 0.000. This is less than the alpha level of 0.005, so we conclude that there is a difference in the speed of combine parts plots with different groups of crops. Review of the medium (average) values of ranks groups, we see that the velocity of this parcel highest in the group with low yields.

However, it is still not known which group are significantly different from each other. For this purpose, there will be used a number of subsequent Mann-Whitney U test between all possible pairs in the group. Therefore will first be applied Bonferroni correction of alpha value to avoid errors of the first kind. Bonferroni adaptation of means to share the alpha value of the 0.05 number of tests to be performed and then use so revised alpha level as a criterion for determining significance to the alpha in all tests together remained at a reasonable level. This would mean more stringent alpha level of 0.05 / 3 = 0.017. For each comparison group after the completion of Mann-Whitney U test will be calculated effect size, ie. strength of relationships between variables and evaluated based on Cohen's criteria.

In the case of comparing the speed of combines in the fields of small and medium yield by Mann-Whitney U test plot was analyzed Z statistics equal to -8.87 with a significance level of p = 0.000, Tab. 4 This leads to the conclusion that there is a significant difference in the average level of speed for these two groups yields. Average value ranges in Tab. 3 for a small contribution to 2639.02 and the average yield of 2279.79. This difference shows the direction of the difference velocity levels. As in calculating the rank lowest value given a value of 1, it is clear that the yield values for speed in the medium yields, on average, received lower rankings.

Table 3. Ranks for combine speed in groups with small and middle yield

	Yield Mass(Dry) (Binned)	*N*	*Mean Rank*	*Sum of Ranks*
Speed	*<= 4.490*	*2475*	*2639.02*	*6531571.00*
	4.491 - 4.970	*2445*	*2279.79*	*5574089.00*
	Total	*4920*		

Table 4. Results of Mann-Whitney U test for combine speed in groups with small and middle yield

Grouping Variable:Yield Mass (Dry) (Binned)	*Speed*
Mann-Whitney U	*2583854.000*
Wilcoxon W	*5574089.000*
Z	*-8.870*
Asymp. Sig. (2-tailed)	*.000*

By using the value of Z in the above results, we can calculate the approximate value of effect size:

$$r = \frac{Z}{\sqrt{N}} \tag{1}$$

Where:

N [-] - total number of cases (observations).

In the case of speed measurements *N* arose every two seconds during the combine on the grounds and along the corresponding walk.

In statistics, the effect size *r* is a measure of strength of the relationship between two variables in a statistical population or its random samples. The impact is calculated based on the data descriptive statistics that convey the estimated value of relationships without any conclusion on whether the apparent relationship in the data reflects a true relationship in the population. In this way, the effect size *r* is the complement of inferential statistics such as the *r* value [10].

In the case of comparing recorded in groups of small and medium-yield triticale in the analyzed plot ($Z = -8.87\ i\ N = 4920$) effect size value is 0.13. It would be considered a very small impact according to Cohen's criteria [11]. In his influential book on statistical significance, Cohen gave his general impression of the level of influence *r* contained in research in order to differentiate less than significant impact. For Cohen, the size of the impact of about 0.1 may be a "small" effect, around 0.3 a "medium" effect and 0.5 to infinity "large" impact. Since then, these values have been widely cited as a standard for assessing the magnitude of the effects that are found in the survey, despite Cohen's personal warning about the inadequacy of the general public. [12]. In the case of comparing recorded in groups with medium and high yield given in Tables 5 and 6 (Z = -19.997 and N = 4901) effect size is just over that. 0286, and it is considered a secondary influence on Cohen's criteria. When comparing the speed of a group of small and large yields given in Tabs 7 and 8, *Z* statistic is equal to -26.110 to 4931 treated cases, the effect size is 0.37 and still be considered a secondary influence on Cohen's criteria.

Table 5. Ranks for combine speed in groups with middle and large yield

	Yield Mass(Dry) (Binned)	N	Mean Rank	Sum of Ranks
Speed	4.491 - 4.970	2445	2856.08	6983104.00
	4.971+	2456	2047.74	5029247.00
	Total	4901		

Table 6. Results of Mann-Whitney U test for combine speed in groups with middle and large yield

Grouping Variable: Yield Mass(Dry) (Binned)	Speed
Mann-Whitney U	2012051.000
Wilcoxon W	5029247.000
Z	-19.997
Asymp. Sig. (2-tailed)	.000

Table 7. Ranks for combine speed in groups with small and large yield

	Yield Mass(Dry) (Binned)	N	Mean Rank	Sum of Ranks
Speed	<= 4.490	2475	2993.29	7408389.00
	4.971+	2456	1934.63	4751457.00
	Total	4931		

Table 8. Results of Mann-Whitney U test for combine speed in groups with small and large yield

Grouping Variable: Yield Mass(Dry) (Binned)	*Speed*
Mann-Whitney U	*1734261.000*
Wilcoxon W	*4751457.000*
Z	*-26.110*
Asymp. Sig. (2-tailed)	*.000*

CONCLUSIONS

Based on these analyzes can not be made a general conclusion about the speed of the combine, depending on yield at harvest triticale. However, the Kruskal-Wallis H test and Chi-Square, mean rank and median, are a powerful and reliable tool for analyzing the dependence of the speed of the combine's yield and can be applied when any need for each plot individually. The analyzed land speed is varied by group. Subsequent Man-Whitney test for the analyzed plot with triticale showed that the rate between the groups differ significantly, but according to Cohen's criteria of small and medium-sized influence of certain based on the value of effect size.

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UTICAJ MASENOG PRINOSA TRITIKALA NA BRZINU ŽETVE

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Sažetak: U ovom radu analizirana je uticaj prinosa tritikala na brzinu kretanja kombajna tokom žetve. Sistem za merenje lokacijski specifičnog prinosa postavljen je na kombajn širine zahvata 6 metara. Nakon žetve prinos je podeljen u tri grupe, kao mali, srednji i velik prinos, i potom pomoću Kruskal-Volisovog H testa analizirana je brzina za svaku grupu prinosa duž parcele. Ustanovljeno je da se na analiziranoj parceli brzine razlikuju i na osnovu srednjih vrednosti rangova grupa zaključeno je da brzina opada sa smanjenjem prinosa, pa se pristupilo naknadnoj analizi razlike među grupama pomoću Man-Vitnijevog U testa. Brzine kretanja kombajna tokom žetve tritikala na analiziranoj parceli razlikuju se statistički značajno pri poređenju sve tri grupe, i to sa malim i srednjim uticajem prema Koenovom kriterijumu.

Ključne reči: *tritikale, brzina, prinos, Kruskal-Volisov H test, Man-Vitnijev U test*

Prijavljen: *Submitted*:	03.10.2014
Ispravljen: *Revised*:	
Prihvaćen: *Accepted*:	25.02.2015.

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 19 – 30

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No. 1, 2015.
pp: 19 – 30

UDK: 631.3:631.552

Originalni naučni rad
Original scientific paper

RATING OF HARVESTER THRESHERS CASE 8120 AND NEW HOLLAND CX 8080

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Abstract: The aim of this work is to review the activity and quality of work of two different combines – CASE 8120 and New Holland CX 8080. The analysis of these two machines is focused on the amount of grain loss, the quality of chopping and spreading residue, the influence of humidity on the amount of grain loss, the influence of humidity on chopping and spreading residue, the power, fuel efficiency.

Either of these combines can be recommended based on the data obtained in this work, but the combine CASE 8120 is more powerful than New Holland. However in practice the difference can be seen only in the mass and area performance. No doubt it was caused by axial-flow treshing method which was used in CASE.

Key words: *harvester threshers, evaluation, technology, quality, brand*

INTRODUCTION

The first harvester threshers combine two major operations, reaping and threshing, are known as early as from the turn of the 19th and 20th centuries. For instance, the Moore´s combined reaper and threshing mechanism are known, patented as a whole in the year 1836. The first self-propelled hervester thresher was constructed by the American G. S.

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Berry. The machine was powered by two steam machines with a mutual boiler. To heat under it, the straw was used. The first self-propelled harvester thresher with petrol motor was developed in the year 1912 probably by G. F. Harris. The Massey-Harris company produced in the year 1922 the harvester thresher with an in-built motor and in the year 1938 the Massey-Ferguson company already produced its first self-propelled harvester thresher which was being sold with success. In the years 1910 to 1930, however, the towed machines were generally preferred, above all from economic reasons. During these years, the harvester threshers also spread throughout Europe. E. g. the Claas company produced in the year 1937 its first towed harvester thresher which was probably the first harvester thresher produced in the European continent. The self-propelled harvester thresher was produced by this firm in the year 1953[2].

In our countries, the first harvester threshers appeared after the year 1945. A tiny amount was imported from Western Europe, bigger distribution was, however, reached by the Soviet semi-trailer harvester thresher of S-6 type. In the year 1957, the self-propelled harvester threshers of S-4 type from the former USSR start to be used, as well as Hungarian machines ADC-343 of appropriately the same efficiency with diesel engine. From 1956 to 1957, Agrostroj Prostějov produces also the harvester thresher ŽM-330. At that time, a new type of harvester threshers from the USSR started to be imported, namely SK-3, which later replaced the SK-4 type. Since 1968, E-512 machines from the former German Democratic Republic have newly been imported to our country, which later became very popular and were probably imported in the biggest amount from all the harvester threshers sold in our country. Since 1974, also the SK-5 Niva and SK-6 Kolos types from the former USSR have also been imported. Since 1979, the harvester threshers E-516 from the former German Democratic Republic have been imported, which later become together with E-512 and E-514 the basic machines for the harvest of cereals used in our agriculture. Besides these, the Polish machines Bizon Z-056 and Z-060, the Romanian ones CP-12 Gloria at a mountain version and exceptionally others are used to a lesser extent. After the year 1989, almost all world producers of harvester threshers get to the republic sooner or later - Case, Claas, John Deere, MDW, Massey-Ferguson, New Holland, etc. [2].

The basic distribution of harvester threshers is realized according to the threshing, i.e. at tangential and axial one, possibly by combination of these systems, the so-called hybrid system. Both tangential as well as axial harvester threshers feature in our experiment. That is why we closer focus only on these two ways of threshing.

At the tangential harvester thresher, the proper threshing mechanism consist of a threshing drum (one or two), most often the threshing one, and a threshing concave. By passing of material between the threshing drum and concave, the crash of material and loosening of grain from ears take place. 70 to 90 % of fine threshed material gets through the threshing concave to the stepped grain pan, or at some types to a set of screw conveyors, in which way the fine threshed material is imported to the refining agent. Further follows the cylinder beater, which prevents from further drift of straw by the threshing drum and guides its flow to the shaker. At some types, the threshing concave is extended below the very cylinder beater, which provides an additional separation and helps a smooth flow of material. The straw, thanks to the movement of keys of shaker, moves away from the thresher. During movement, parallel layering and shaking takes place, in which way the rest of fine threshed material is loosened, which is brought through the refining agent. For the improvement of separation, various tedding mechanisms or drum with withdrawable fingers are placed above the shaker, which intend to secure complete separation of fine threshed material before the end of the shaker. The threshed material is imported to the refining agent which consist of air box and air flow from the blower. Here occurs the separation of wheat from chaff which moves away from the thresher of spikelets that come back by the carrier of spikelets for finishing the threshing. The refined grain is transported by the conveyor of grain to the bin [3].

Harvester threshers with axial threshing and separation mechanism differ a lot from the classical tangential ones. From the name it results that the threshing mechanism is placed in the harvester thresher in such a way that the material is obliged to move on during threshing in the direction of axis of the drum, i. e. axially. The inclined conveyor to which individual adaptors are connected is somewhat different, it tends to be shorter and generally smaller. The threshed material is transported from the inclined conveyor to the axial threshing and separation mechanism. Some producers placed in front of the proper axial also the tangential vaned robot which pulls the plant material out of the inclined conveyor and throws it quickly to the axial drum. By this way, the smooth and continuous flow of material is reached. Blades of the insertion screw together with the guide gib pull the threshed material in the gap between the rotating combined rotor and fixed threshing and separation covering. In the first part of the rotor, there is threshing between it and the concave, i. e. loosening of grain from ears. The cereal material rotates at the same time between the rotor and covering at a speed equal to approximately one third of circumference speed of the rotor and by means of guide gibs of covering of the axial rotor it is moved in the direction of the axis of rotation. In the second part of the mechanism there occurs separation of grain from straw (rough threshing). The diameter of the threshing concave can be at the whole length the same or graded, as e. g. at the harvester thresher John Dere 9880 STS. This construcion, while the concave is enlarged, enables the plant material to expand during the flow by the mechanism. The finger rotor of the separator uses in this way the system of pulling and loosening of grain from the plant material. In this way the winding of straw on the rotor is restricted and, on the other hand, this arrangement decreases the energy intensity. The straw passes further in the same way thanks to guide gibs from the mechanism away, most often to the crusher, and is spread to the width of advance of the harvester thresher [3].

The basic agricultural requirements for harvester threshers can be characterized in the following way:

- machines are destined for gathering of cereals, corn for grain, legumes, oilseeds, clover plants and grasses for seed, possibly other grain crops.
- the executed operations are: mowing of ground cover or gathering from rows, transportation of material to the threshing mechanism, its threshing, separation of rough and fine threshed material, transportation of seed to the bin and straw to the row or crushing and spreading of straw through the stubble field.
- the unmowed ground cover of cereals with grain yield of up to 10 $t \cdot ha^{-1}$, height of plants from 0.3 to 2.5 m. Humidity of grain of up to 30 %, humidity of straw of up to 40 %. Proportion of grain to straw from 1:0.8 to 1:2.5. Ground cover vertical as well as depressed (turbulent) to all directions [1].
- during swathing, the ground cover is mowed by front self-propelled windrower with the width of advance of 4 to 6 m. Width of row of 0.8 to 1.4 m, height of row of 0.2 to 0.6 m. The stalks are placed to the longitudinal axis of a row at the angle

of 15 to 25°. The row cannot be placed to the track of wheels. The quantity of ears for swathing in immediate touch with soil of up to 5 %.

- specific flow (permeability) at standard harvester threshers moves from 8 to 20 $kg \cdot s^{-1}$, which is corresponded by widths of advances of headers from 4 to 9 m, capacities of grain bins of up to 10 m^3 with filling height to the means of transport of over 3 m, engine powers of up to 300 kW, working speeds infinitely variable from 1 to 8 $km \cdot h^{-1}$ and productivities of up to 4 $ha \cdot h^{-1}$. Slope accessibility of 8 to 12°, pressure to the soil below 0.15 MPa.
- specific flow of slope harvester threshers is considered to be smaller and this is corresponded by widths of advances of headers, bins volumes, engines powers, work speeds and production rates. Slope accessibility of 20°, pressure to the soil below 0.15 MPa.
- standard as well as slope harvester threshers should have the possibility of being equipped with these adaptors with fitting: pick up mechanism for divided gathering, carrier-mounted crusher of straw, chassis for header, ar-conditioned cabine. Standard harvester threshers moreover: adaptor for gathering of corn for grain, adaptor for gathering of sunflower and rape.
- harvester threshers should have the following features of automatization: indication and signalling of losses of grain behind shakers and cleaning machine, indication of decline of nominal revolutions of the main shafts of working mechanisms, counting of hectares, slope threshers, and then automatic equalizing threshers in traverse as well as longitudinal direction at slopes up to 20°. Perspectively, standard harvester threshers should have: automatic guidance of machine to the grain wall, automatic regulation of traverse speed according to indicated losses of grain and according to permeability, automatic regulation of threshing mechanism, shakers and fining agent, mapping of yields.
- harvester threshers have to work with high operational reliability, must comply with regulations on safety and health protection during work, regulations on operation on public communications, possibly with regulations on transport by railway.
- the machine has to be attended by one worker
- regular height of stubble field, infinitely variable from 70 to 600 mm. Losses of grain during direct gathering of up to 1.5 % (specific from biological crop), from that behind the header of up to 0.5 %, behind the thresher of up to 1 %. Losses of grain during divided gathering of up to 2 %, from that after the withdrower of up to 0.5 %, behind the pick up mechanism of up to 0.5 % and behind the thresher of up to 1 %. Losses of grain from cylinder losses of up to 0.5 %. Damage of grain of up to 3 %. Content of cereal ingredients and impurities in a grain (in the bin) of up to 3 % (specific), from that of impurities of most highly up to 1 %. Width of a row of straw of up to 150 cm.

The harvest of seed crops, especially then of cereals and pulses, can at present only with difficulties be imagined without harvester threshers. These are complicated machines which develop all the time, their productivity increases, losses and operational costs decrease. The most important task which is required from harvester thresher is the separation of grain from straw by means of separation.

Wheat was harvested throught combine harvester or tresher. Labor shortage and timely completion of harvesting operation attracts farmers to harvest wheat crop throught combine harvester. This facilitates to make land available for next crop sowing operation. The damage loss of wheat grain is the main disadvantage of harvesting machinery utilization [5].

From the times of the first harvester threshers which were drawn by several pairs of horses, already a row of years passed, and that is why we at present commonly meet harvester threshers of the power of over 300 kW, the most efficient ones may dispose even of engines of the power exceeding 400 kW.

Today is also more and more frequently used GPS. It consists of three basic systems - the space segment, the control segment and the level of user segment [4]. Use this control system guides the combine harvester with an accuracy of up to 1-3 cm, or be drawn up yield and moisture maps.

MATERIALS AND METHODS

In the experiment, two harvester threshers were used – Case 8120 and New Holland CX 8080. The most detailed characteristic of individual machines is stated in Tabs 1 and 2.

Table 1. Technical specifications of harvester thresher New Holland CX 8080

Year of manufacture	*2007*	
Engine	*Iveco Cursor, 290 kW, volume of 9 litres*	
Cutter mechanism	*Biso, 750 cm*	
Threshing and separation mechanism	*Tangential threshing mechanism with rotating separator, 6 key shakers of the area of 5,93 m^2*	
Threshing drum	*Diameter [mm]*	*750*
	Width [mm]	*1560*
	Revolutions of threshing drum [min]	*305 - 905*
	Angle of wrapping of threshing basket [°]	*111*
	Area of the main threshing basket [m^2]	*1,18*
Area of sieves [m^2]	*6,5*	
Size of grain bin [l]	*10 500 l*	

Table 2. Technical specifications of harvester thresher Case 8120

Year of manufacture	*2010*	
Engine	*Iveco Cursor, 313 kW, volume of 10,3 litres*	
Cutter mechanism	*MacDon, 915 cm*	
Threshing and separation mechanism	*Axial, 1 rotor, hydraulic changeover*	
Threshing drum	*Diameter [mm]*	*762*
	Length [mm]	*2638*
	Revolutions of threshing drum [min]	*220 - 1180*
	Angle of wrapping of threshing basket [°]	*180° (360°)*
	Area of the main threshing basket [m^2]	*x*
Area of sieves [m^2]	*6,5*	
Size of grain bin [l]	*12 300 l*	

Ideal conditions, that is to say measurement at both harvester threshers on the same day at one field, when both harvester threshers would have the same conditions both as for the yield, weed infestation of ground cover, humidity, as for climatic conditions of the field, were not possible. The characteristic of fields and climatic conditions was chosen so that it suited the following:

- Crop: winter wheat
- Terrain: flat land
- Yield [Ø]: 6 - 7 $t \cdot ha^{-1}$
- Grain humidity [Ø]: 12,5 - 13,5%
- Weather: clear, windlessness, 20 - 25°C
- Ground cover: depressed from max. 5%, minimal weed infestation

The consumption of harvester thresher can be found out according to the relationship (1):

$$m = \frac{O_l}{n_{ha}} \tag{1}$$

Where:
m [$l \cdot ha^{-1}$] - consumption of PHM,
O_l [l] - volume of refilled fuel,
n_{ha} [ha] - harvested area.

The time of working engagement of machine will be found out by direct measurement and consists of definite partial categories of times. For our measurement, especially 4 times are important, according to which we find out 4 various performances – time T_1, for performance W_1 (effective). Time T_{02} for performance W_{02} (operational). Time T_{04}, for performance W_{04} (productive). Time T_{07} for performance W_{07} (general).

Distribution of times:
T_1 - major time
T_2 - incidental time (emptying of bin, rotation)
- $T_1 + T_2 = T_{02}$ = operational time
T_3 - time for maintenance
T_4 - time for clearing of faults
- $T_1 + T_2 + T_3 + T_4 = T_{04}$ = productive time
T_5 - time of idle times due to operation
T_6 - time for initiation and termination of SM work
T_7 - time of other idle times
- $T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 = T_{07}$ = general time

The areal performance of harvester thresher can be found out from the area “P“ for the definite time “T“. Harvester threshers were monitored during working shift and times were recorded in time picture. We find out 4 kinds of performance – effective, operational, productive and general. Individual areal performances can be calculated according to equations (2),(3),(4),(5).

- Effective areal performance:

$$pW_1 = \frac{P}{T_1} \tag{2}$$

- Operational areal performance:

$$pW_{02} = \frac{P}{T_{02}} \tag{3}$$

- Productive areal performance :

$$pW_{04} = \frac{P}{T_{04}} \tag{4}$$

- General areal performance

$$pW_{07} = \frac{P}{T_{07}} \tag{5}$$

Where:

$pW_1, pW_{02}, pW_{04}, pW_{07}$	[ha·h^{-1}]	- areal performance in given time interval,
P	[ha]	- processed area during measurement ,

Weight performance is understood to be the found weight of sample "V_z" for a definite time "T". Harvester threshers were monitored during working shift and times were recorded in time picture. As at areal performance, we find out also here 4 kinds of performance – effective, operational, productive and general. Individual weight performances can be found out by means of equations (6),(7),(8),(9).

- Effective weight performance:

$$mW_1 = \frac{m}{T_1} \tag{6}$$

- Operational weight performance:

$$mW_{02} = \frac{m}{T_{02}} \tag{7}$$

- Productive weight performance:

$$mW_{04} = \frac{m}{T_{04}} \tag{8}$$

- General weight performance:

$$mW_{07} = \frac{m}{T_{07}} \tag{9}$$

Where:

$mW_1, mW_{02}, mW_{04}, mW_{07}$	[t·h^{-1}]	- weight performance in given time interval,
m	[t]	- weight of sample V_z during measurement ,
T_1	[h]	- major time,
T_{02}	[h]	- operational time,
T_{04}	[h]	- productive time,
T_{07}	[h]	- time of measurement in given time interval.

The quality of crushing of straw can be calculated from Eq. (10). For sampling we use the canvas which we place between front and rear wheels of the harvester thresher. To this area, we spread one more canvas in shape of rectangle of the length of cutter bar of the harvester thresher and of the width equal to specific area of 1m^2. After driving of the harvester thresher to the ground cover, we carry the canvas for such a long time until the harvester thresher is completely fulfilled, then we put in down, place to it produced rectangle and let it drive over by rear wheels. The crusher of harvester thresher disperses for us consequently crushed after-harvest residues to the rectangle produced by us. Individual fractions separate, their measurement and evaluation are done. Consequently, individual fractions divide into individual classes according to straw length (0 - 5cm, 5,1 - 7,5cm, 7,6 - 10cm, 10,1 - 12,5cm, 12,6 - 15cm, 15,1 cm and more). The quality of crushing of straw can be found out according to Eq. (10).

$$K_d = \frac{f_i}{m_c} 100 \tag{10}$$

Where:
K_d [%] - percentage representation of individual classes,
f_i [g] - weight of individual fraction,
m_c [g] - total weight of after-harvest residues on the taking canvas .

Harvest losses can be found out in such a way that the checked area $K_{p2} = 1m^2$ is defined perpendicularly to the row. The working engagement of lath is equal to the length of this rectangle, the width is calculated according to Eq. (11). From the checked rectangle, we can find out relative losses or absolute losses. It is necessary to remove from the control area all grains including the grains which are found in possible unthreshed ears.

$$w = \frac{K_{p2}}{d} \tag{11}$$

Where:
w [m] - width of rectangle,
d [m] - length of rectangle (according to cutter mechanism).

Total relative losses Z_{rc} are determined by calculation according to Eq. (12). Both before-harvest as well as harvest losses found out from the control area K_{p2} are concerned. The yield of grain (m_z) is the weight of grains in $kg \cdot ha^{-1}$, which is harvested by harvester thresher and is found out directly at the detector of harvester thresher.

$$Z_{rc} = \frac{m_{kp}}{m_z} \cdot 100 \tag{12}$$

Where:
Z_{rc} [%] - total relative losses,
m_{kp} [$kg \cdot m^{-2}$] - weight of grains from the control area K_{p2},
m_z [$kg \cdot ha^{-1}$] - yield of grain.

Calculation of relative losses of the harvester thresher Z_{rs} can be found out from formula (13).

$$Z_{rs} = \frac{(m_{ko} - m_p)}{m_z} \cdot 100 \tag{13}$$

Where:
Z_{rs} [%] - relative losses of harvester thresher,
m_{ko} [$kg \cdot ha^{-1}$] - weight of grains from the control area K_{p2},
m_p [$kg \cdot ha^{-1}$] - before-harvest losses,
m_z [$kg \cdot ha^{-1}$] - yield of grain.

RESULTS AND DISCUSSION

The performance of harvester thresher is one of the most important parameters which interests us as users. Areal and weight performance, as well as time picture are demonstrated in individual tables for individual harvester threshers.

Table 3. Time picture of harvester threshers during harvesting

Time	*Case 8120 [h]*	*New Holland [h]*
T_1	3,85	3,9
T_2	0,95	1,1
T_3	0,9	1,1
T_4	0,22	0,15
T_5	0,1	0,2
T_6	0,8	0,7
T_7	1,13	0,85
T_{02}	4,8	5
T_{04}	5,92	6,25
T_{07}	8	8

Weight performance of harvester threshers is demonstrated in Tab. 4.

Qualitatively cut straw usually contains 88-93% of particles smaller than 80 milimetres. The smaller the particles, the better they decompose in soil. Unsufficiently cut after-harvest residues result in longer decomposition time and in this way they enable the origin of undesired moulds, which can transfer to the succeeding crop. The quality of crushing at individual threshers is demonstrated in Fig. 1. The average humidity of material was in both cases of 13,2%.

Table 4. Weight performance of threshers during harvesting of winter wheat

	Case 8120 $[t \cdot h^{-1}]$	*New Holland $[t \cdot h^{-1}]$*
mW_1	75,71	68,21
mW_{02}	59,01	53,20
mW_{04}	47,24	42,56
mW_{07}	36,91	33,25

Areal performance of harvester threshers is demonstrated in Tab. 5.

Table 5. Areal performance of threshers during harvesting of winter wheat

	Case 8120 $[ha \cdot h^{-1}]$	*New Holland CX $[ha \cdot h^{-1}]$*
pW_1	9,96	8,97
pW_{02}	7,77	7,00
pW_{04}	6,22	5,60
pW_{07}	4,87	4,38

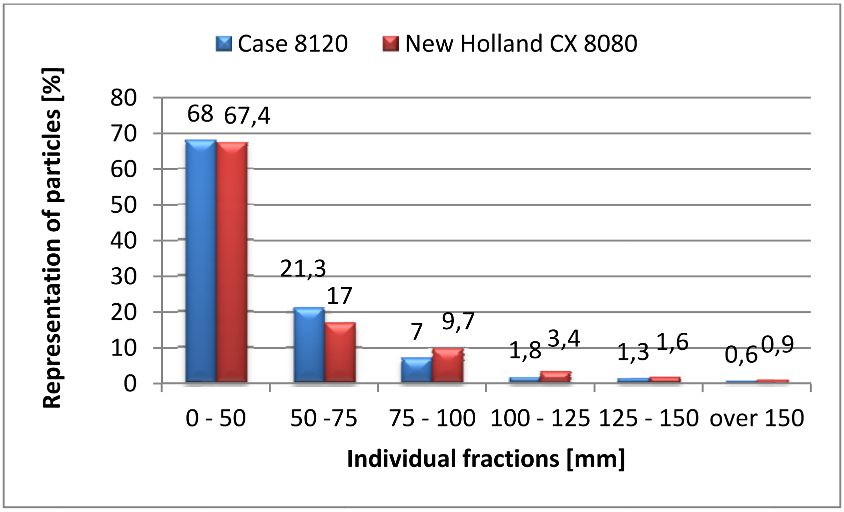

Figure 1. Percentage expression of quality of crushing of after-harvest residues at wheat

Size of absolute losses during harvesting of winter wheat is demonstrated at both harvester threshers in Tab. 6. The size of consumption of fuels is an important agent during calculation of costs for harvested hectare. The consumption of individual threshers is demonstrated in Tab. 7.

The fact, however, remains that there is tendency towards increasing of engine performance, notably at axial threshers. At present we commonly meet performances exceeding 400 kW. Almost everywhere these are machines with axial way of threshing. It is no exception that these harvester threshers have mowing adaptor of the advance exceeding 10 metres.

Table 6. Size of absolute losses at winter wheat

Harvester thresher	*Measurement*	*Size of harvest losses Z_{rc} [%]*
Case 8120	*harvesting of wheat*	*0,29*
New Holland CX	*harvesting of wheat*	*0,37*

Table 7. Size of consumption of fuels during mowing the wheat

Harvester thresher	*Consumption PHM [l.ha^{-1}]*
Case 8120	*17,9*
New Holland CX	*17,7*

I personally drive such machine and I think that with incresing advance decrease the crossings over the field, consequently also the consumed fuel. It is, however, necessary to consider the suitability of lands for such a cutter bar. Ideal conditions are undoubtedly in Southern Moravia or in Slovakia in the area of the Žitný island. Here the lanscape is practically flat. If the owner of the machine is, however, freelancer or firm dealing with services, it usually travels around all the state, many times also in more states. Then it is worth considering to buy a cutter bar which is smaller or invest money and buy a flexible mowing adaptor, e.g. of the MacDon company. I personally have only positive experience with this cutter bar. The disadvantage of this mowing adaptor is the price which moves around the double of classical mowing adaptor.

I do not recommend, however, bars with the advance bigger than 9,15 metres to tangential harvester threshers. These machines are not only sufficient by their performance, but mainly neither by their permeability of the whole threshing and separation system. In some cases, a bar at tangential threshers of the maximal advance of 7,5 metres is even recommended.

CONCLUSION

The harvester threshers, that is to say, did not operate on the same lands, the measurement, however, was realized in almost the same conditions (weather, terrain, yields).

By calculation of harvest losses, especially then of absolute losses, it was found out that the harvester thresher Case 8120 was doing better. Its losses moved up to 0,29 %, in comparison with the losses of New Holland, which were of 0,37 %. Both machines reached outstanding results as regards losses. The literature states the maximal permissible losses between 2 - 3%. The fact, however, remains that the extension of losses results from the crop being harvested and many times also from the concrete type of seed. The biggest share in losses will always have, however, the operation of harvester thresher. The setting of machine is different for every crop, humidity and sometimes also directly for the strain, and it requires maximal effort.

One of the most important factors is the performance of the harvester thresher. Both in weight performance as well as in the areal one, the harvester thresher Case 8120 was again doing better, harvesting 36,91 $t \cdot h^{-1}$, that is to say 4,87 $ha \cdot h^{-1}$. New Holland harvested 33,25 $t \cdot h^{-1}$, that is to say 4,38 $ha \cdot h^{-1}$.

During crushing and cutting the straw, the harvester threshers were virtually equal. The quality of crushing, demonstrated in picture 1, indeed marks as better the harvester thresher Case, nevertheless both of them met the criterion so that 80% of cut straw ranged between 0 - 80 mm.

The consumption of fuels was at both machines virtually equal. By 0,2 $l \cdot ha^{-1}$ it was better at the harvester thresher New Holland, where the consumption of 17,7 $l \cdot ha^{-1}$, in comparison with 17,9 $l \cdot ha^{-1}$ at the harvester thresher Case, was reached. In practice it is, however, valid that the bigger is the yield of the field, the bigger the consumption. In case of our experiment, the field treated was always that of winter wheat of the yield over 7 $t \cdot ha^{-1}$. In case of harvesting the rape of the average yield of 2,5 $t \cdot ha^{-1}$, the consumption lower by 2 - 4 litres can be regarded. Also in this case, the yield and climatic conditions matter. Also the width of the header should be taken into this account.

The harvester threshers Case and New Holland met all agrotechnical characteristics from the point of view of losses, performance and quality of crushing of after-harvest residues. During harvesting, the harvester thresher by the Case company proved totally as better. The differences were, however, minimal at both products.

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OCENA RADA KOMBAJNA CASE 8120 I NEW HOLLAND CX 8080

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***Sažetak*:** Cilj ovog rada je da analizira rad i kvalitet rada dva različita kombajna – CASE 8120 i New Holland CX 8080. Analiza ove dve mašine je usmerena na količinu gubitaka zrna, kvalitet seckanja i rasturanja ostataka, uticaj vlažnosti na količinu gubitaka zrna, uticaj vlažnosti na seckanje i rasturanje ostataka, snagu i efikasnost potrošnje goriva.

Na osnovu rezultata ovog rada, oba kombajna se mogu preporučiti, ali kombajn CASE 8120 ima veću snagu od kombajna New Holland. Pored toga, u praksi se razlika može primetiti samo u performansama mase i vazdušne struje. Nema sumnje da je uzrok bila vršidba metodom aksijalnog toka, koja se koristi kod kombajna CASE.

Ključne reči: *kombajni, ocena, tehnologija, kvalitet, robna marka*

Prijavljen: *Submitted*:	05.06.2014
Ispravljen: *Revised*:	25.02.2015.
Prihvaćen: *Accepted*:	07.03.2015.

Univerzitet u Beogradu
Poljoprivredni fakultet
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Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 31 – 40

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No. 1, 2015.
pp: 31 – 40

UDK: 631.354.2

Originalni naučni rad
Original scientific paper

REFINEMENT AND EVALUATION WHEAT STRAW COMBINE FOR BETTER STRAW QUALITY

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Abstract: Straw combine is very popular machine in Punjab for the retrieval of wheat straw. It was observed that quality of wheat straw obtained from straw combine is inferior due to more dirt content as compare to harambha thresher. Therefore, the straw combine was developed with straw bruising and sieving system for the removal of dirt. Dirt was quantified by total ash content and acid insoluble ash. Field evaluation of the modified straw combine and laboratory analysis of collected sieved straw sample was carried out. Two level of concave bar spacing (10 and 14 mm), three feed rates (14, 16.5 and 19 $q \cdot h^{-1}$) and three cylinder speeds (28.45, 32.25 and 36.04 $m \cdot s^{-1}$) were selected as operational parameter. It was observed that mechanical sieving of straw was well enough for the separation of dirt. Percent reduction of total ash content and acid insoluble ash due to sieving increases with decrease in feed rate and increase in concave bar spacing. Average straw length and split straw percentage was found to well within acceptable level at 14 mm concave bar spacing. Net specific fuel consumption was found to be decreases with increase in feed rate and concave bar spacing and increases with increase in cylinder speed.

Key words: *straw combine, average straw length, split straw percentage, total ash content, acid insoluble ash.*

INTRODUCTION

The production and productivity is directly related with farm mechanization i.e. power availability. The availability of power in Punjab is 3.5 $kW \cdot ha^{-1}$, which is highest

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in the country while average power availability in agriculture for whole country is 1.5 kW·ha^{-1} [5]. This mechanization was achieved by the developing various machinery based on crop and need. Straw combine is a machine which cut, collect, bruise and convey the straw in wire mesh trailer. A straw combine essentially consist of five main units, namely stubble cutting unit, feeding unit, straw bruising unit, blowing unit and straw collection unit which contains a trailer enclosed by wire mesh to collect bhusa during straw combine operation and to separate dust particles. The machine can be operated by tractor of 40-50 hp. The power is transmitted from PTO shaft. Average height of cut stubbles was 48 mm above the ground. About 96% of the total mass passing through the straw combine was chopped into lengths of < 50mm and only 4% of the mass was > 50 mm long. Average straw recovery was about 52% and recovered wheat grain amounting to 22 kg·ha^{-1} [2]. But it was observed that the straw harvested by straw combine contains soil dirt which increases total ash content and acid insoluble ash which is harmful for the animal health. As per recommendation of Department of Animal nutrition GADAVASU, Ludhiana, Punjab, ash content should not exceed 7-8 % and acid insoluble ash should not exceed 4-5% [1]. Whereas, in case of sample obtained from straw combine, values of ash content (13.72%) and acid insoluble ash (6.61%) exceeded the recommended values, thus indicating that the straw produced by straw combine contain more dirt as compared to harambha thresher.

A study on separation of dirt content from bruised wheat straw was done by Bhardwaj (2008) to investigate the design parameter for the development of dirt separation system for wheat straw combine. It was observed that sieving is best method for dirt separation from bruised straw. To attach sieving system on the existing straw combine, blower of the machine has to be removed. Preliminary trails have shown that in the absence of blower, material does not come out of the threshing/ bruising drum and machine chokes. Therefore, there is a need to modify a straw bruising system of existing machine to fit a sieving system on it. Therefore, the study was undertaken to improve the performance of straw combine by developing a new straw bruising system and by providing a sieving system in straw combine.

MATERIAL AND METHODS

A tractor operated modified straw combine was developed in the department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana, Punjab.

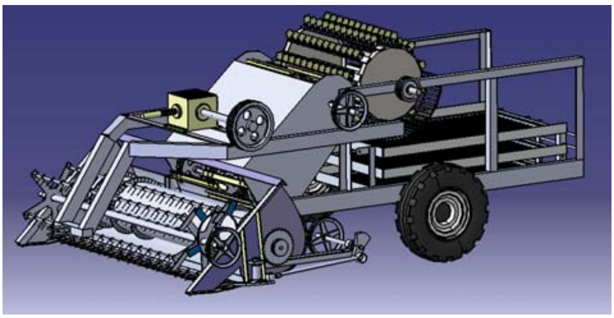

Figure 1. Computer aided 3D model of conceptual modified wheat straw combine

Before developing actual working machine, computer aided 3D model of conceptual machine was made to give exact idea for fabrication. The performance and evaluation studies were conducted in the research farm of Punjab Agricultural University, Ludhiana, during May-June, 2013.

General descriptions of the modified wheat straw combine

The improved wheat straw combine was fabricated with the following modifications:
1. Straw bruising unit with chain type feeding system.
2. A rectangular sieving system for sieving of bruised straw which was absent in existing straw combine.
3. Blower unit was absent.

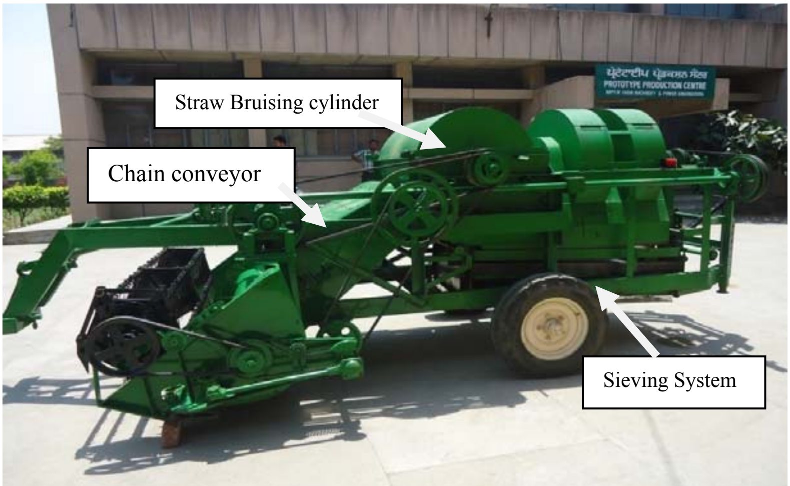

Figure 2 Modified wheat straw combine

Other components of modified straw combine similar to that of the existing straw combine includes; cutter bar, reel, platform auger, type of bruising cylinder i.e. serrated tooth type, and the supporting frame. The cutting unit has a same cutting width to maintain equal capacity as the existing one. A platform auger is located below the chain type feeding conveyor to convey the material. The chain type feeding conveyor has same as combine harvester which was absent in the existing straw combine. It is constructed to convey the feed into the bruising cylinder. The straw bruising cylinder was made up of no. of serrated blades arranged on steel bars. This cylinder drum is mounted on the frame with bearing and is rotated in a perforated trough-like member, called the “Concave”. The width of the bruising unit was kept smaller than the existing straw combine. This was to enable the proper feeding of straw from chain conveyor to cylinder which leads to easy bruising. The sieving system was placed exactly at the bottom of bruising cylinder and it consists of two sieves one above the other. Sieving unit catch the bruised straw from cylinder and separate the dirt from the straw through a reciprocating motion provided by the main source of power of the straw combine. The blower unit was removed. The straw was collected at end of the sieve. The transmission unit consists of a gear box, cylinder pulley, a cutting unit pulley and a shaker pulley. The 65 hp tractor was used for evaluating the modified straw combine. The machine was operated by PTO of tractor. By using gearbox with ratio 1:1, power was transmitted to the cutting, collecting and bruising components of straw combine. The straw combine has a structural frame on which all other components were mounted. The brief specifications are given in Tab. 1.

Table 1 Specification of modified straw combine

Sr. No.	Parameter	Specification
1.	Power source	2 p tractor
2.	Overall dimension of machine Length Width Height	 5050 2320 1820
3.	Chain conveyor	
	Opening width Front opening height Rear opening height	1030 500 260
4.	Bruising drum	
	Type Width Tip diameter of cylinder with blade No. Of bars No. Of blades and their spacing on each bar	Serrated tooth type blade 1003 725 12 13,76
5.	Baffle plate	
	Type No. Plate Location	Serrated type blade 1 Adjacent to concave
6.	Straw cleaning sieve	
	Type of sieve shaker Type and size of sieves Effective size of sieve	Reciprocating type Wire mesh, 1550 x 860 1530 x 820
	Hole dia. Upper sieve Lower sieve	 4 0.208 mm
	Inclination towards the end	8°

All line dimensions in mm

Evaluation Procedure

The independent variables that affect the machine performance were included in the study i.e. concave bar spacing, cylinder peripheral speed and feed rate. Feed rate of the straw combine was dependent upon the width of cut, crop density, forward speed, and stalk cut length. In this study feed rate was varied with machine forward speed. The present study was related to the different aspects of quality of bruised straw obtained from newly fabricated straw combine. Therefore, straw quality and dirt content were included as dependent variables. Apart from this net specific fuel consumption was a very important variable which has an obvious importance. It is ratio of net fuel consumption and feed rate. Net fuel consumption is the difference between actual fuel consumed for operation of machine at load and no load. In order to assess the dirt content of bruised straw, two types of tests namely; total ash content and acid insoluble ash were conducted. Straw quality was determined on the basis of average straw length and percent splitting of bruised straw. For measuring fuel consumption, fuel meter was used. The experiment was planned with a Factorial *CRD* to analyze the effect of three independent variables on the dependent variables. On the basis of level of independent parameter, there were 18 (3×3×2) treatment combinations in the complete study. Each treatment of field evaluation was replicated three times. The length of treatment was decided 50 m whereas effective cutting width was 1.75 m. The wheat harvested field area i.e. 4725 m² (54×50×1.75) was divided into three equal block of area 1575 m² for three replication i.e. each experiment was replicated in three different block for its replication. Each block was again divided into two parts in which two concave bar spacing C1 i.e. 10 mm and C2 i.e 14 mm were used. Again each part was divided into 9 equal of strip i.e. 1.75 × 50 m to conduct experimental treatment.

RESULTS AND DISCUSSION

Effect of concave bar spacing, cylinder speed and feed rate on net specific fuel consumption

Analysis of variance showed that concave bar spacing, cylinder speed and feed rate were significant effect at 5% level of significance. Fig. 3 shows that the net specific fuel consumption increases with increase in cylinder speed. This is because of more impact force by high speed blade of cylinder relative to the material. The highest net specific fuel consumption was observed at lower feed rate and higher cylinder speed at concave bar spacing 10 mm.

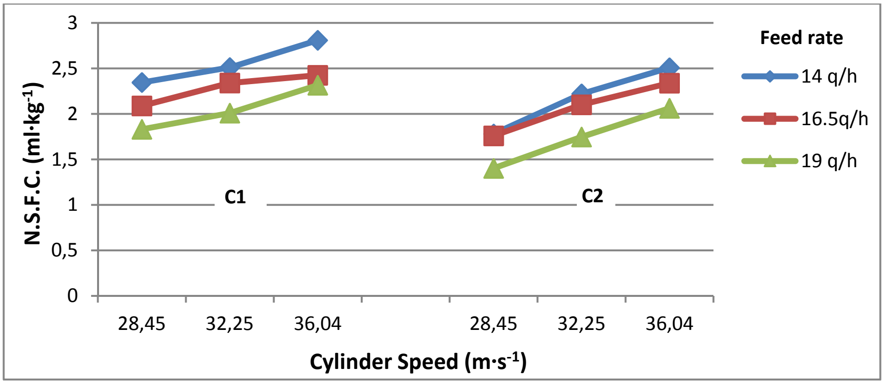

Figure 3. Effect of independent variables on net specific fuel consumption

During operation, net fuel consumption increased with increase in feed rate, because at higher feed rate, the bruising cylinder has to handle more straw mass. I t was supported by Thakur and Garg, 2007 [6]. But decrease in net specific fuel consumption was due to the reason that net fuel consumption increased with decreasing rate i.e. increase in net fuel consumption was relatively lesser as compared to increase in feed rate. From Fig. 3, it is clear that the net specific fuel consumption decreased with increase in concave bar spacing. The obtained result supported by Venkata *et al* (2009) [7] in case of total and specific energy. As concave bar spacing increases, lesser resistance was offered for the movement of straw in the cylinder. On increasing concave bar spacing from 10 mm to 14 mm, net specific fuel consumption reduces by 0.566 ml·kg^{-1} at feed rate of 14 q·h^{-1} and cylinder speed of 28.45 m·s^{-1}. This was due to wider concave opening allow early and easy passing of bruised straw through the concave which cause less straw crushing. It also results in reduction of net specific fuel consumption.

Effect of concave bar spacing, cylinder speed and feed rate on average straw length of bruised straw

From the statistical analysis it was revealed that the concave, cylinder speed and feed rate significantly affected average length of straw at 5% level of significance. All interactions were not significant at 5% level of significance.

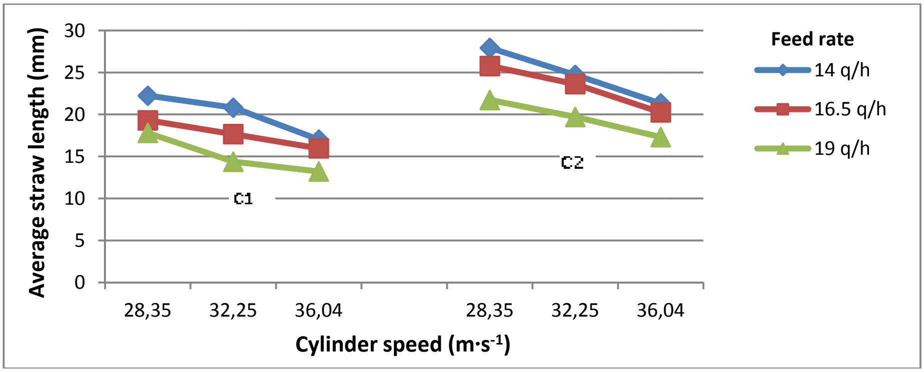

Figure 4. Effect of independent variables on average straw length

It can be seen from the Fig. 4, the cylinder speed and feed rate, have indirect relation with average length of bruised straw. This may be due to the fact that amount of straw to be cut increased by increased feed rate and also due to higher feed rate straw was properly compressed which lead to less slippage of straw and more retention time of crop in concave meanwhile, the number of cut per unit time increases and this lead to decrease in the average length of bruised straw and vice-versa. Similar kind of effect was observed by Singh *et al* 2011 [4]. The highest average length of bruised straw in case of *C1* was found to be 20.23 mm at cylinder speed of 28.45 m·s^{-1} and feed rate of 14 q·h^{-1}. In contrast, the lowest average length of bruised straw was found to be 12.22 mm at cylinder speed of 36.04 m·s^{-1} and feed rate of 19 q·h^{-1}. Average length of bruised straw in case of *C1* was acceptable (≤ 25 mm and c.v. ≤ 40%) only at the feed rate of 14 q·h^{-1} in the combination with cylinder speed of 28.45 and 32.25 m·s^{-1} and at feed rate of 16.5 q·h^{-1} in the combination with cylinder speed of 28.45 and 32.25 m·s^{-1}. Similar kind of result obtained for concave bar spacing of 14 mm. It was observed that the high value average length of bruised straw was found to be (25.26 mm) at cylinder speed of 28.45 m·s^{-1} and feed rate of

14 q·h^{-1} and quite the reverse, the low value average length of bruised straw was found to be (16.07 mm) at cylinder speed of 36.04 m·s^{-1} and feed rate of 19 q·h^{-1}. The obtained result in case of concave bar spacing was in line with Venkata *et al* 2011 [8]. At feed rate of 14 q·h^{-1} and cylinder speed of 28.45 m·s^{-1}, average length of bruised straw is not acceptable because C.V. is greater than 40%, which is beyond the permissible limits.

Effect of concave bar spacing, cylinder speed and feed rate on straw split percentage of bruised straw

Analysis of variance revealed that the effects of the concave bar spacing, cylinder speed, and feed rate significantly affects on split straw percentage at the 5% level of significance. Among the all interaction, first order interaction between concave and cylinder speed was significant at 5% of confidence level. It was observed that at *C1*, by increasing the cylinder speed from 28.45 to 36.04 m·s^{-1}, split straw percentage increased from 93.49% to 96.96%, from 94.27% to 97.95%, and from 95.26% to 98.43% at the feed rates of 14, 16.5 and 19 q·h^{-1} respectively. Similarly, by increasing the feed rate from 14 to 19 q·h^{-1}, split straw percentage increased from 93.49 to 95.25%, from 95.02 to 96.55%, and from 96.96 to 98.43% at the cylinder speed of 28.45, 32.25 and 36.04 m·s^{-1} respectively.

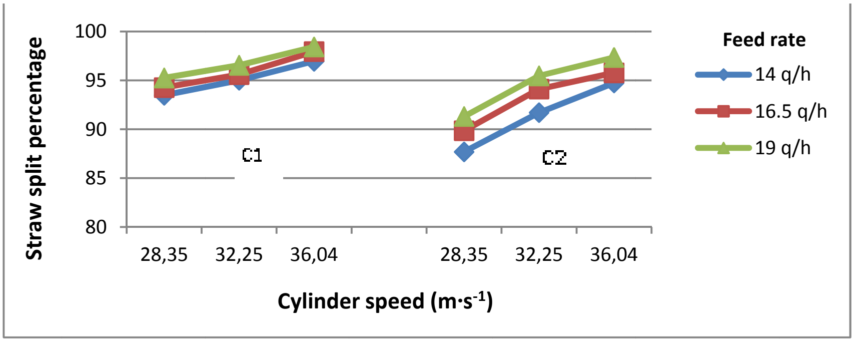

Figure 5 Effect of independent variables on split straw percentage

At concave *C2*, similar trend was observed. The obtained results for *C2*, indicates that on increasing cylinder speed from 28.45 m·s^{-1} to 32.25 m·s^{-1} and at fixed feed rates of 14, 16.5 and 19 q·h^{-1} split straw percentage increased from 87.69 to 94.74%, 89.85 to 95.78% and 91.31 to 97.35% respectively. Again, by increasing feed rate from 14 to 19 q·h^{-1}, the percentage of split straw was increased from 87.69 to 91.31%, 92.71 to 95.47% and 94.74 to 97.35% at fixed cylinder speeds of 28.45, 32.25 and 36.04 m·s^{-1} respectively. The straw split percentage obtained at concave bar spacing of 14 mm and cylinder speed of 28.45 m·s^{-1} for all level of feed rate was not acceptable due to split straw percentage was < 92%.

Effect of independent parameter on reduction of total ash content

Statistical analysis indicates that there is a significant effect of the feed rate and concave bar spacing on the dependent variables i.e. reduction of total ash content while cylinder speed is not affecting significantly at 5% level of significance. The first order interaction between concave bar spacing and cylinder speed was significant.

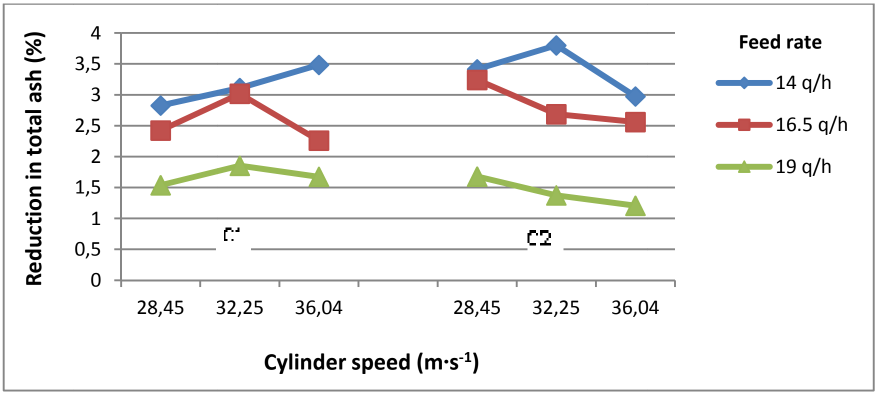

Figure 6. Effect of independent parameter on reduction of total ash content

Effect of independent parameter on reduction of acid insoluble ash

The statistical analysis shows that concave bar spacing and feed rate were significant effect on the reduction of acid insoluble ash. Also, the first order interaction of concave bar spacing and cylinder was a significant effect. With increase in feed rate from 14 $q \cdot h^{-1}$ to 19 $q \cdot h^{-1}$, percent reduction of acid insoluble ash decreases. This was because of same reason as observed for total ash content. In case of concave bar spacing of 10 mm and 14 mm, it was found that maximum reduction in total ash content was observed at 14 mm concave bar spacing as compared to 10 mm concave bar spacing.

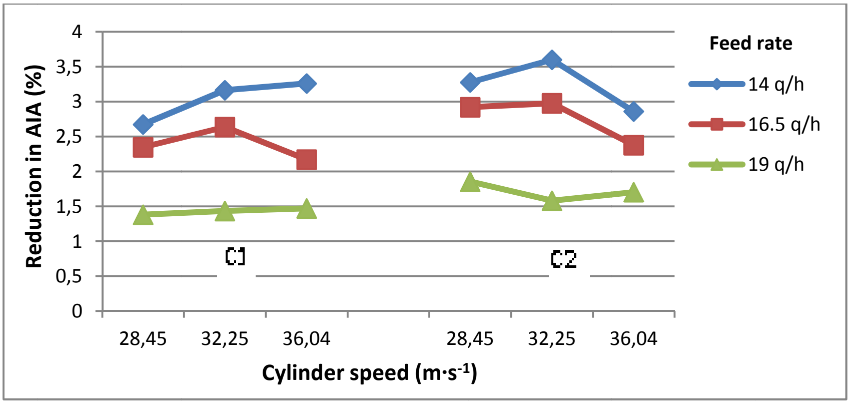

Figure 7. Effect of independent variables on reduction of acid insoluble ash

This is because of larger concave opening which gives early exit to chopped straw through the concave and thereby decreasing the fine stuff in straw. Moreover, straw bruising was avoided which result in larger straw length. Larger straw reduce resemblance between chaff and dirt which may differentiate straw and dirt which help for better separation. The lowest value of acid insoluble ash in bruised straw was found to be 5.08%.

CONCLUSIONS

1. Net specific fuel consumption was decreases with increase in feed rate but increase with cylinder speed. The maximum net specific fuel consumption observed at concave bar spacing of 10 mm, 14 $q \cdot h^{-1}$ feed rate and 36.04 $m \cdot s^{-1}$ cylinder speed.
2. Average straw length of concave bar spacing of 14 mm (C2) was well within acceptable range i.e.≤25 mm along with ≤ 40% C.V. and splitting of straw (≥95%) for all combination of cylinder speeds of 32.25 and 36.04 $m \cdot s^{-1}$ except at feed rate of 14 $q \cdot h^{-1}$ and cylinder speed of 28.45 $m \cdot s^{-1}$.
3. Maximum reduction in percent total ash content and acid insoluble ash was observed at 14 $q \cdot h^{-1}$ feed rate and 14 mm concave bar spacing due to sieving of straw.
4. The best performance combination of independent variables was at concave bar spacing of 14 mm, feed rate of 14 $q \cdot h^{-1}$ and cylinder peripheral speed of 32.25 $m \cdot s^{-1}$ for the best quality straw, maximum reduction as well as minimum dirt content (total ash content and acid insoluble ash).

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UNAPREĐENJE ŽITNIH VRŠALICA U CILJU POBOLJŠANJA KVALITETA SLAME

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Sažetak: Žitne vršalice su veoma popularne u Punjab oblasti u Indiji. Primećeno je da je kvalitet slame nakon ubiranja klasičnim žitnim kombajnom, lošiji zbog većeg prisutva nečistoća, u poređenju sa žitnom vršalicom. Iz tog razloga se radilo na konstrukciji kombajna za slamu koji je opremljen uređajem sa čišćenje i prosejavanja slame. Prilikom ispitivanja kvaliteta rada, količina nečistoće odstranjena iz slame, je određena preko količine pepela nakon sagorevanja i sadržaja, u kiselini, nerastvorenog pepela. Poljsko ispitivanje je takođe sprovedeno a uzorci slame su doneti na labaratrijsko ispitivanje. Dva nivoa rastojanja rešetke (10 i 14 mm), tri protoka (14, 16.5 i 19 $q \cdot h^{-1}$) i tri brzine bubnja (28.45, 32.25 i36.04 $m \cdot s^{-1}$) su uzeti kao parametri rada. Uočeno je da je mehanički sistem prosejavanja slame zadovoljavajući u slučaju otklanjanja nečistoća. Procenat smanjenja ukupne količine pepela i količine pepela nerastvorenog u kiselini, se povećava sa smanjenjem protoka i sa smanjenjem rastojanja između rešetki sita. Prosečna dužina slame i udeo polomljene slame su bili u prihvaltjivim granicama kod minimalnog rastojanja između rešetki sita od 14 mm. Ukupna specifična potrošnja goriva se smanjivala sa povećanjem protoka mase i rastojanja između rešetki, dok se, sa povećanjem brzine obrtanja bubnja, povećavala.

Ključne reči: *žitna vršalica, prosečna dužina slame, polomljena slama, ukupan sadržaj pepela, u kiselini ne rastvoriv pepeo*

Prijavljen: *Submitted*:	30.05.2014.
Ispravljen: *Revised*:	
Prihvaćen: *Accepted*:	22.03.2015.

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 41 – 49

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No.1, 2015.
pp: 41 – 49

UDK: 631.3

Originalni naučni rad
Original scientific paper

EFFECT OF SELECTED PARAMETERS ON TRAY ANGLE FOR SMOOTH DROPPING OF SEEDLINGS IN SEMI-AUTOMATIC VEGETABLE TRANSPLANTER

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Abstract: Studies were conducted on a single row semi-automatic vegetable transplanter to determine the optimum tray angle in the feeding and metering mechanism at different seedling ages and different types of seedlings. The optimum tray angle at which the finger trays have been fitted to the carrying chain has been determined through laboratory experimentation. The experiments have been designed as a three factors *C.R.D.* with four replications. The percentage of seedlings properly dropped (*PSPD*) increased with finger tray angle from 20 to 30 degree where per cent dropping was observed irrespective of type of crop and length of seedlings. The *PSPD* decreased as the finger tray angle was increased above 30 degree. Chilli had the highest *PSPD* at any particular tray angle setting in comparison to other crops whereas tomato had the least per cent of seedlings properly dropped. The smaller seedlings (100-150 mm) as well as larger seedlings (250-300 mm) showed relatively more difficulty in dropping properly than the medium length (150-250 mm) seedlings.

Key words: *Seedlings, finger trays, dropping tube, conveyer chain*

INTRODUCTION

India is the second largest producer of vegetables in the world next to China with a production of 162.18 million tons from an area of 9.20 million hectares [1]. Vegetable production in India stands at 7% of the world production. Manual transplanting of seedlings, weeding and harvesting are the most labour consuming operations in

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vegetable cultivation. Transplanting of vegetable seedlings in developed countries like U.S.A., China, Holland, Japan and Canada is being mechanically done with either fully automatic or semi-automatic vegetable transplanters. However, in India, transplanting of vegetable seedlings is done manually all over the country, as very few works has been made to develop vegetable transplanters. The mechanical transplanting has been considered the most promising option, as it saves labor, ensures timely transplanting and attains optimum plant density that contributes to high productivity [9]. Some attempts have been made in recent years on semi-automatic vegetable transplanters for adoption under our conditions. In automatic type vegetable transplanters both feeding and metering of seedlings are automatic where as in semi-automatic type feeding is done manually and metering is done mechanically. Generally, semi-automatic transplanters use bare root seedlings.

Various seed drills and transplanters with different metering mechanisms have been developed, evaluated and reported by various researchers as reported in literature, i.e. [2] [3] [4] [7] [13] [16]. Metering systems must be designed to maintain desired plant to plant distance in a row. The seed and plant spacing majorly depends on the machine technical variables such as the type of seed pickup mechanism, machine operating speed, overall gear ratio between drive wheel and seed plate, and also on seed quality to some extent [15]. Garg et al. reported the development and evaluation of a single row semi-automatic transplanter with single cone type metering mechanism with a drop chute for placing seedlings into a furrow by gravity [6]. Two operators alternatively place a single seedling at one time. The rotating plate strikes the cone opening it, and the seedling moves in the drop chute pipe. Bare root chilly seedlings transplanted with the machine had missing of 14.47 per cent and the machine had a low capacity. Semi-automatic potato planter and sugarcane planter with revolving magazine type metering mechanism can plant 90 tubers of potato and 60 sets of sugar cane per minute by chilli transplanter with finger type metering mechanism [14]. Craciun and Balan developed a rotary cup type planting unit with open cup bottoms and supported on a horizontal stationary plate with an opening through which the seedling was discharged [5]. This type of planting device allows the operator to rapidly place several seedlings and then have a brief time to untangle or remove seedlings from cells rather than having to maintain exact timing for each seedling [12]. Transplanter with such type of metering unit can plant 50-80 seedling/min/row, depending on the required plant spacing. But this type of planting unit was used for planting pot seedlings in semi-automatic vegetable transplanter. Satpathy et al. reported that in two row tractor operated vegetable transplanter with finger type metering mechanism; plant missing was within acceptable limit of 3-4 per cent at 1 to 1.2 $km \cdot h^{-1}$ with two operators feeding seedlings per row [14]. Narang et al. tested semi-automatic vegetable transplanter with revolving magazine type metering mechanism and reported that average plant missing in case of brinjal was 2.22 to 4.44 per cent and the quality of feeding decreased with increase in plant missing and ranged between 95.57 to 97.78 per cent [11]. Conveyor-Type Planting Unit One advantage of this type of unit is that a substandard seedling can be easily identified using a suitable vision system and replaced with good-quality seedlings as the seedlings are carried by the conveyor [8]. In this study small trays called finger trays have been designed in semi-automatic vegetable transplanter on which the seedlings are to be kept manually. The seedling feeding and metering mechanism consists of a feeding chain carrying ten finger trays, a bevel assembly and a chain and sprocket assembly. The optimum tray angle at which the finger trays have been fitted to the carrying chain has been determined through laboratory experimentation.

MATERIAL AND METHODS

The following considerations have been made while designing the feeding system for the vegetable transplanter.

Small trays called 'finger trays' have been designed on which the seedlings are to be kept manually. The dimension of the finger trays have been fixed in such a way that the largest seedling placed on it can move freely along with the chain (Fig. 1)

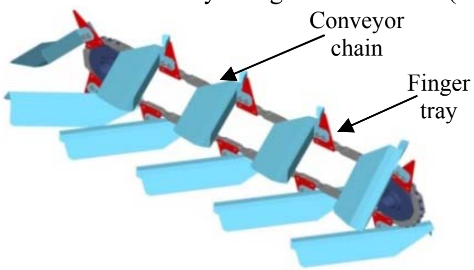


Figure. 1 Design of finger tray and metering mechanism

Laboratory test was conducted to find out the angle (*β*) in horizontal direction between finger tray on which the seedlings were kept manually and the moving chain. This angle *β* helps in dropping the seedling in such a way that the seedlings are properly guided into the drop tube. The levels of the factors were decided after observing the preliminary tests.

The test was statistically planned as a three factor completely randomized design (*CRD*) with four replications as shown in Table 1.

Table 1. Design of experiment for Laboratory Test

Sl No.	Factor number	Factor description	Levels
1	Factor A	Angle β	$\beta_1 = 20°$, $\beta_2 = 25°$, $\beta_3 = 30°$, $\beta_4 = 35°$
2	Factor B	Crop C	C_1 = Brinjal, C_2 = Chilli, C_3 = Tomato, C_4 = Cabbage, C_5 = Knolkhol
3	Factor C	Length of seedling L	L_1 = 100-150 mm, L_2 = 150-200 mm, L_3 = 200-250 mm, L_4 = 250-300 mm

RESULTS AND DISCUSSION

The purpose of finding the finger tray angle was to drop the seedlings in such a way that the roots of the seedlings were always guided towards the dropping tube. The mean of the replications of the experiment has been shown in Tab. 2.

Table 2. Mean of seedlings dropped properly into the funnel of seedling dropping tube

Tray angle	Crop	Seedlings dropped properly into the funnel			
		L = 100-150	L = 150-200	L = 200-250	L = 250-300
20°	Chilli	8.660 (75)	9.150 (84)	9.150 (84)	8.060 (65)
	Brinjal	8.293 (69)	8.660 (75)	8.800 (78)	7.750 (60)
	Tomato	8.370 (70)	8.370 (70)	8.060 (65)	7.750 (60)
	Cabbage	8.215 (68)	8.657 (75)	8.587 (74)	8.297 (70)
	Knolkhol	8.442 (71)	8.660 (75)	8.940 (80)	8.730 (76)
25°	Chilli	8.940 (80)	9.220 (85)	9.220 (85)	8.870 (79)
	Brinjal	8.940 (80)	9.220 (85)	9.220 (85)	8.660 (75)
	Tomato	8.940 (80)	8.940 (80)	8.660 (75)	8.655 (75)
	Cabbage	8.800 (78)	9.150 (84)	9.150 (84)	8.660 (75)
	Knolkhol	8.940 (80)	9.220 (85)	9.490 (90)	8.940 (80)
30°	Chilli	10 .0(100)	10 .0 (100)	10 .0 (100)	9.810 (96)
	Brinjal	10 .0 (100)	10 .0 (100)	10 .0 (100)	9.875 (98)
	Tomato	10 .0 (100)	10 .0 (100)	10 .0 (100)	9.617 (93)
	Cabbage	9.938 (99)	10 .0 (100)	10 .0 (100)	9.872 (98)
	Knolkhol	9.938 (99)	10 .0 (100)	10 .0 (100)	9.810 (96)
35°	Chilli	9.150 (84)	9.353 (88)	9.490 (90)	9.220 (85)
	Brinjal	9.010 (81)	9.220 (85)	9.220 (85)	8.940 (85)
	Tomato	8.870 (80)	9.220 (79)	9.220 (85)	8.940 (80)
	Cabbage	9.010 (81)	9.010 (85)	9.010 (85)	9.010 (81)
	Knolkhol	9.010 (81)	9.288 (86)	9.217 (85)	8.940 (80)

* *Data in the parentheses are actual data in percentages (rounded to integer)*

** *Data outside the parentheses are transformed data for analysis of variance.*

Effect of Length of crop on *PSPD*

The percentage of different lengths of seedlings of chilli, brinjal, tomato, cabbage and knolkhol properly dropped through the seedling tube irrespective of tray angle setting has been shown in Fig. 2.

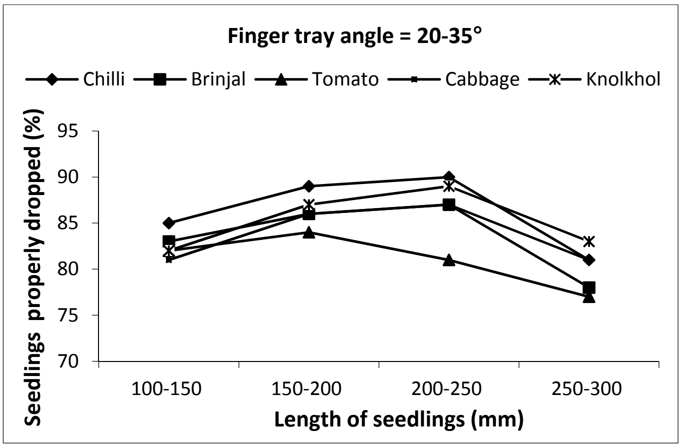


Figure 2. Effect of type of crops and length of seedlings on percentage of seedlings properly dropped (PSPD)

It was found that the average PSPD increased from 85, 83, 81 and 82 to 90, 87, 87 and 89 in case of chilli, brinjal , cabbage and knolkhol respectively as the length of seedlings increased from 100-150 mm to 200-250 mm and decreased to 81, 78, 81 and 83 when the length of seedlings increased to 250-300 mm. But in case of tomato, *PSPD* increased from 82 to 84 as the length of seedlings increased from 100-150 mm to 150-200 mm and then decreased to 81 and 77 when length of seedling is 200-250 mm and 250-300 mm respectively. The smaller seedlings (100-150 mm) as well as larger seedlings (250-300 mm) showed relatively more difficulty in dropping properly than the medium length (150-250 mm) seedlings except tomato, where the smaller seedlings dropped easily than larger seedlings.

The ANOVA for the effect of seedling length and type of crop on tray angle is shown in Table 3. It was evident from the ANOVA that all the three factors viz. finger tray angle, type of crop and length of seedlings affect *PSPD* significantly (at 1% level).

Table 3. Analysis of variance for the effect of seedling length and type of crop on tray angle (CRD)

Source	*DF*	*Sum of squares*	*Mean square*	*F Value*	*Prob*	*SEM*	*CD*	
							1%	*5%*
Factor A	*3*	*88.203*	*29.401*	*2106.8518*	*0.00*	*0.0132*	*0.0485*	*0.0368*
Factor B	*4*	*3.316*	*0.829*	*59.4078*	*0.00*	*0.0148*	*0.0543*	*0.0412*
AB	*12*	*2.422*	*0.202*	*14.4619*	*0.00*	*0.0295*	*0.1083*	*0.0822*
Factor C	*3*	*7.352*	*2.451*	*175.6031*	*0.00*	*0.0132*	*0.0485*	*0.0368*
AC	*9*	*1.546*	*0.172*	*12.3123*	*0.00*	*0.0264*	*0.0969*	*0.0735*
BC	*12*	*1.371*	*0.114*	*8.1864*	*0.00*	*0.0295*	*0.1083*	*0.0822*
ABC	*36*	*3.047*	*0.085*	*6.0643*	*0.00*	*0.0591*	*0.2170*	*0.1646*
Error	*240*	*3.349*	*0.014*					
Total	*319*	*110.606*						
Coefficient of variation: 1.29%								

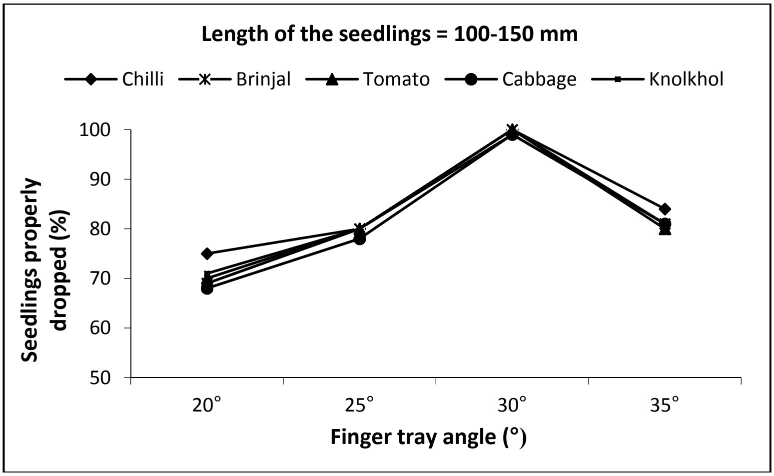
Factor A : Finger tray angle (Level = 4)
Factor B : Seedlings of five different crops (Level = 5)
Factor C : Length of seedlings (Level = 4)
No. of replications: 4
Dependant variable: Seedlings properly dropped, %

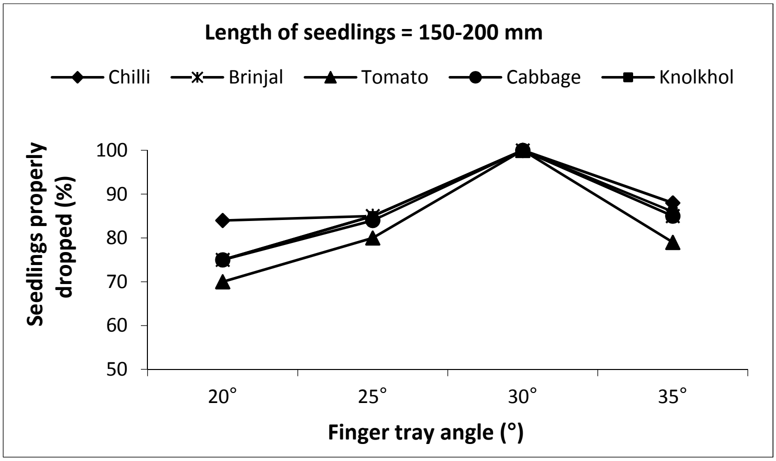
Effect of type of crop on finger tray angle

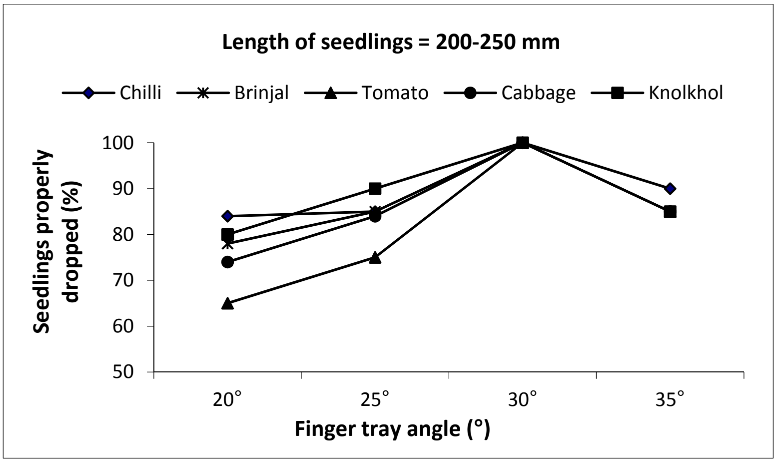
The percentage of seedlings properly dropped (*PSPD*) with different crops at different setting of tray angle has been presented in Fig. 3.

Chilli had the highest *PSPD* at any particular tray angle setting in comparison to other crops whereas tomato had the least per cent of seedlings properly dropped (Fig. 2 and 3). This was observed because chilli had the least foliar development and hardy stem compared to other crops under study, where as tomato stem was very soft and it had more foliar development. The percentage of seedlings properly dropped in case of other crops lie in between chilli and tomato.

As seen from the Fig. 3, the percentage of seedlings properly dropped increased from 76.875 to 99.063, 70.313 to 99.375, 66.25 to 98.125, 71.25 to 99.063 and 75.625 to 98.75 in case of chilli, brinjal, tomato, cabbage and Knolkhol respectively with finger tray angle increases from 20° to 30°.


Length of the seedlings = 100-150 mm
Chilli
Brinjal
Tomato
Cabbage
Knolkhol
Seedlings properly dropped (%)
100
90
80
70
60
50
20°
25°
30°
35°
Finger tray angle (°)


Length of seedlings = 150-200 mm
Chilli
Brinjal
Tomato
Cabbage
Knolkhol
Seedlings properly dropped (%)
100
90
80
70
60
50
20°
25°
30°
35°
Finger tray angle (°)


Length of seedlings = 200-250 mm
Chilli
Brinjal
Tomato
Cabbage
Knolkhol
Seedlings properly dropped (%)
100
90
80
70
60
50
20°
25°
30°
35°
Finger tray angle (°)

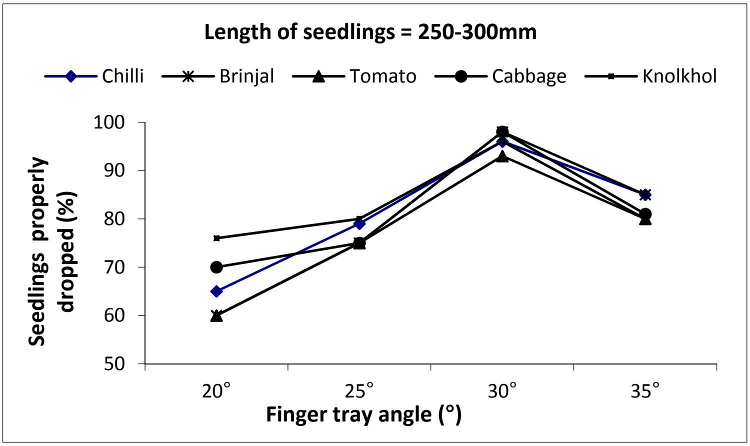


Figure 3. Effect of finger tray angle on percentage of properly dropped seedlings through seedling dropping tube with four levels of seedling lengths

So nearly cent per cent dropping was observed irrespective of type of crop and length of seedlings in 30° tray angle. The *PSPD* decreased from 99.063 to 86.563, 99.375 to 82.813, 98.125 to 82.188, 99.063 to 83.125 and 98.75 to 83.125 in case of chilli, brinjal, tomato, cabbage and Knolkhol respectively as the finger tray angle was increased from 30° to 35° irrespective of type of crop and length of seedlings. Therefore, finger tray angle of 30° has been taken as optimum value for designing the feeding system of the semi-automatic vegetable transplanter.

CONCLUSIONS

During the process of designing the semi-automatic vegetable transplanter, from laboratory test it was found that finger tray angle of 30° is the optimum value for smooth dropping of seedlings from the feeding unit irrespective of type of crop and length of seedlings. Medium length (150-250 mm) seedlings showed better dropping from feeding unit except tomato where as tomato seedlings dropped properly at 100-150 mm size seedlings. The smaller seedlings (100-150 mm) as well as larger seedlings (250-300 mm) showed relatively more difficulty in dropping properly than the medium length (150-250 mm) seedlings [10].

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UTICAJ UGLA POSTAVLJANJA TRANSPORTERA SADNICA NA KVALITET SADNJE KOD POLUAUTOMATSKE SADILICE ZA POVRĆE

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Sažetak: Istraživanje je imalo za cilj ispitivanje jednoredne poluautomatske sadilice za povrće, kako bi se odredio otimalan ugao zahvatanja i ulaganja različitih tipova sadnica rasada u zemljište. Optimalni ugao vođice na kojoj su prihvatni prsti pričvršćeni na noseći lanac, je određen u labaratorijskim uslovima. Eksperiment je urađen kao trofaktorijalni C.R.D. sa četiri ponavljanja. Procenat sadnica rasada, pravilno postavljenih (PSPD) se povećavao sa uglom postaljvaja od 20 do 30 stepeni. Za ovaj dijapazon se pokazalo da tip sadnice i njena dužina ne utiču na kvalitet sadnje. *PSPD* se smanjivao sa povećanjem ugla postavljanja vođice, preko 30 stepeni. Čili sadnice su imale najviši *PSPD* u poređenju sa ostalim kulturama, dok je *PSPD* bio najniži kod paradajza. Sitnije sadnice (100-150 mm) kao i krupnije (250-300 mm) su pokazale poteškoće prilikom sadnje u poređenju sa srednje razvijenim (150-250 mm) sadnicama.

Ključne reči: *rasad, vođica sa hvatačima, mehanizam za ulaganje rasada, lanac konvejera*

Prijavljen: *Submitted*:	11.07.2014.
Ispravljen: *Revised*:	20.03.2015.
Prihvaćen: *Accepted*:	23.03.2015.

Univerzitet u Beogradu
Poljoprivredni fakultet
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Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 51 – 60

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No. 1, 2015.
pp: 51 – 60

UDK: 634.37

Originalni naučni rad
Original scientific paper

MINIMIZING TRANSPORTATION LOSSES IN FRESH FIG (*Ficus carica* L.) FRUITS

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Abstract: The study was undertaken to measure the damage to packaged fig (*Ficus Caria L.*) during transportation and consequent storage. The data presented in this study will assist farmers and packaging material designers in selection of packaging materials to reduce damage in transit. Fresh harvested fig fruits at commercial maturity free from bruises and injury were packed in CFB boxes of 10 kg capacity with internal packaging materials *viz.* newspaper lining, polyethylene foam, polyurethane foam. The packaged fruits were transported for transportation distance of 500 km. After transportation fruits were observed for physiological loss in weight, total soluble solids, firmness and decay loss at room temperature. The results showed that the per cent of damaged fruits differed significantly with different packaging materials. As expected, based on previous work, fruit damage was found to be more in the CFB box with paper lining. Fruits packed in polyurethane foam were more firm with reduced increase in TSS. The results showed that a minimum amount of damage occurred in CFB box with polyurethane compared to all other packaging materials. Decay loss of the fruits was also low in CFB box with polyurethane foam followed by polyethylene foam after five day of storage.

Key words: *fig, packaging material, transportation, losses.*

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INTRODUCTION

Fig (*Ficus carica L.*) belongs to the family *Moraecae* and is the native of Southern Arabia. Its mention has been made as early as 2900 B.C. by King *Urukagina* for its medicinal use. The world's area and production of fig fruit recorded for the year 2009 are 4,53,622 ha, and 11,83,248 tones, respectively. India stands 12th in the world for production of fig (20,700 tonnes) from an area of 6000 ha. Its commercial production is limited to a few pockets of Maharashtra and Karnataka [1]. In Karnataka it is cultivated on commercial scale in northern districts *viz.,* Bellary, Raichur, Gulbarga and Koppal. The total area under fig cultivation is 1498 ha with production of 13,643 tonnes. Bellary (1078 ha and 9234 tonnes) ranks first in area and production followed by Koppal (96 ha and 1178 tonnes), Raichur (78 ha and 1092 tonnes) and Gulbarga (115 ha and 867 tonnes).

The post-harvest losses of fruits and vegetables are high in tropical countries particularly in India and it is in the range of 15-40 %. Fruits and vegetables are subjected to different types of mechanical forces during harvesting, storage and transportation. These forces are impact, vibration, and abrasion, compression, bruising and cut by sharp edge. Vibration injury may cause only one of these damages, or all three. Various studies have been carried out to assess the effects of these stresses on fresh fruits [2]. The total loss of fresh fruits and vegetables during transportation and distribution has been estimated to be 30 % in China [3] whereas 20 % of grains harvested gets spoiled every year [4]. Damage caused by transport vibration was assessed on different species of fruits and vegetables, such as cling peaches, apricots [5], pears [6], apples and tomatoes [6] and potatoes [7].

Fig is one of the most perishable climacteric fruit. To obtain optimum flavor, fig fruit should be harvested when almost fully ripe. However, at this stage, it is soft and susceptible to deterioration [8], limiting post-harvest life to 2 days under ambient and 7 to 14 days under refrigeration condition [9]. Softening and post-harvest diseases limit the storage period and shelf life of figs. Very little research has been done to identify the suitable packaging materials for minimizing the transportation losses and extending post-harvest life of fresh figs. An investigation on effects of vibration and packaging materials on three important fig varieties grown in Turkey showed that packaging materials affected vibration injury of fruit. In local transportation, cardboard boxes were more suitable for transportation than wooden ones [10]. The most important cause of deterioration is incidence of microbial molds and rots that take advantage of the easily damaged epidermis and the high sugar content of figs.

The protection of fig fruits quality in the value chain from harvesting to market is very important. Vibration often causes some damage to the perishable fruits in transportation and reduces their quality [11]. The fruit injury due to vibration is related to the transportation characteristics of vehicles, packaging boxes and the condition of the roads [2]. Sommer (1957b) [12] attempted to prevent transit injury to Bartlett pears by packing the pears in protective materials such as shredded paper, shredded polyethylene film, and 1 in. polyethylene film disks. Sommer found that these materials reduced but did not prevent transit injury. Schulte Pason *et al*. (1990) [13] studied impact bruise damage of apples packed in polyethylene bags, and pulp or foam tray containers for transportation distances up to 584 km (363 mi). Schulte Pason observed upon arrival that the number of unbruised apples packed in bags were greater than those packed in pulp trays and were less than those packed in foam trays. Shulte Pason [13] also found that the number of impacts greater than 20 g were highly correlated to the percent of bruised apples. In contrast it have observed that the skin of Bartlett pears can be severely discolored when vibrated at acceleration levels slightly above 1 g for periods as short as 30 min [14].

Lack of information on post-harvest handling of fig fruits has resulted in huge losses to the tune of 20 to 30 % to the farmers and traders thereby making the fig production uneconomical. Principal causes for post-harvest losses are infection by pathogens, rough handling, improper packaging, mode of transportation and unhygienic storage condition. It is estimated that total losses due to spoilage ranges from 30 to 40 %. In this context, there is a pressing need to identify a suitable packaging system that protects fresh figs against mechanical injuries during post-harvest handling, transportation and storage.

MATERIALS AND METHODOLOGY

Fig fruits (*Poona* variety) at commercial maturity were hand harvested from the orchard located at Shrinivas Nagar village of Bellary district. Bruised and injured fruits were discarded and sound fruits were selected.

Sorted good quality fruits were packed in seven different kind of internal packaging materials *viz.* newspaper lining, paper shavings, polyurethane foam sheet. Packaging materials and their treatments are given below and depicted in Figs. 1, 2 and 3.

P_1 - CFB box with newspaper lining (Control)
P_2 - CFB box with polyethylene foam sheet.
P_3 - CFB box with polyurethane foam sheet.

Figure 1. CFB box with newspaper lining (Control)

Fresh fig fruits having almost same size and without any damage or skin disorders were selected and labelled for observing different responses. One set of 30 fruits were labelled for estimation of physiological loss in weight (*PLW*), another set of 20 fruits for visual observations to estimate decay loss. The labelled fruits were randomly placed in the CFB box.

Figure 2. CFB box with polyethylene foam

Figure 3. CFB box with polyurethane foam

Packed fruits were loaded in transport vehicle and transported for 500 km transportation distances. After transportation fruits were stored at ambient condition and were observed immediately after one day of transportation. Physiological loss in weight (PLW) and decay loss of the fruit was estimated during the storage of fresh fig fruits up to complete spoilage of fruits.

Determination of physiological loss in weight (PLW)

Observations were recorded every day in respect of the physiological loss in weight of fruits. The weights of the fruits were measured by using a weighing balance of ±0.001g accuracy. Physiological loss in weight was expressed as per cent loss in weight using the formula given below [15].

$$WL = \frac{IFW - OFW}{IFW} \cdot 100 \tag{1}$$

Where:
WL [%] - loss in weight,
IFW [g] - initial weight of fruits,
OFW [g] - weight of fruits on the day of observation.

Firmness

The firmness of the fig fruit was determined using the Texture Analyzer (Make: Stable Micro System; Model: Texture Export Version 1.22). Penetration tests with the help of texture analyzer was used to measure the firmness of fig [16]. The following instrument settings were used during the experiment:

- Type of probe used - 5 mm cylindrical probe
- Test module - Measure force of penetration
- Test option - Return to start
- Pre-test speed - 5.0 $mm \cdot s^{-1}$
- Test speed - 1.0 $mm \cdot s^{-1}$
- Post-test speed - 10.0 $mm \cdot s^{-1}$
- Distance - 10 mm
- Trigger force - 25 g
- Load cell - 5 kg

Three fruits from each treatment were analysed for the firmness. Penetration test was carried out at three different positions on the fruit. After running the test, the force required to penetrate into the fruit for given distance was directly obtained from the data recorder (Computer). Finally, the averages of three fruits from each treatment and replicate and at three different positions were taken as the firmness of fig fruit in that treatment [17].

Estimation of decay loss

The fruits were observed for decay loss every day till complete spoilage of fruits occurred during storage. The decay loss due to bruising was calculated by using the following equation.

$$DL = \frac{DF}{TF} \cdot 100 \qquad (2)$$

Where:
DL [%] - decay loss,
DF [-] - number of decayed fruits,
TF [-] - total number of fruits in the cartoon box.

RESULT AND DISCUSSION

The fig fruits were inspected and observation on physiological loss in weight (PLW), Firmness and decay loss. Data was recorded according to the methodology described earlier and presented in Tab. 1.

In the present experiment, the fig fruits showed a gradual increase in the physiological loss of weight with advancement of the storage period in all the treatments, irrespective of packages used. The peak surge in PLW coincided with ripening of fruits. This is mainly attributed to the continuous loss of moisture and other nutrients as the fruits are alive and are actively involved in the physiological processes like respiration and transpiration [18]. Among the packaging materials used, physiological loss in weight of fresh fig fruits was recorded maximum in *CFB* box with newspaper lining. After third day of transportation, maximum weight loss of 17.15 % was observed in in P_1 (*CFB* box + newspaper lining). P_3 (*CFB* box + polyurethane foam sheets) and P_2 (*CFB* + polyethylene foam sheets) recorded minimum physiological loss in weight (14.15 % and 15.33). On the last day of storage (Fig. 1) P_3 (*CFB* box + polyurethane foam sheets) recorded minimum physiological loss in weight (28.65 %).

Table 1. Effect of transportation on fresh fig fruits

Storage days	*PLW*			*Firmness*			*Decay*		
	P1	*P2*	*P3*	*P1*	*P2*	*P3*	*P1*	*P2*	*P3*
Day 1	*6.85*	*5.88*	*5.55*	*3.28*	*3.76*	*4.01*	*25.63*	*16.50*	*10.20*
Day 3	*17.15*	*15.33*	*14.15*	*2.74*	*3.11*	*3.20*	*68.75*	*68.25*	*31.25*
Day 5	*31.44*	*29.74*	*28.86*	*1.31*	*1.50*	*1.80*	*100.00*	*86.88*	*65.60*
C. V.	*3.75*			*3.49*			*3.60*		

P1 - CFB box with newspaper lining (Control)
P2 - CFB box with polyethylene foam
P3 - CFB box with polyurethane foam sheet

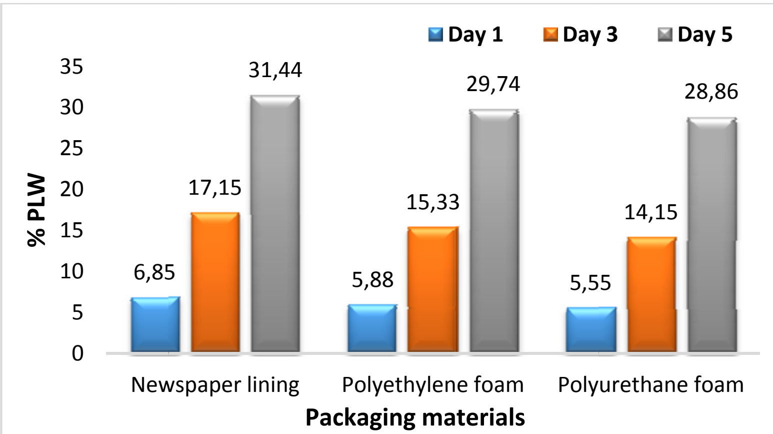

Figure 1. Effect of transportation on physiological loss of fresh fig fruits

Mechanical damage increases the respiration rate [19]. Sommer [12] found that vibration damaged fruit loses moisture more rapidly than undamaged fruit, further reducing the quality of the injured fruit. The higher respiration rate resulted in higher transpiration of water from the fruit surface which led to increase in percentage of weight loss [20]. Therefore as the PLW of fresh fig fruits in P_3 (*CFB* box + polyurethane foam sheets) is minimum it shows the minimum mechanical damage to the fruits and hence the cushioning property of polyurethane foam protects the fruits during transportation.

Effect of different packaging materials for transportation on firmness of the fresh fig fruits during storage at ambient condition are presented in Tab. 1. Polyurethane foam protected the fruits from vibration. More heavily injured fruits had a higher rate of softening during storage at ambient temperature [5]. It was also observed from the Fig. 2, that the firmness of the fig fruits decreased with the duration of the storage period.

The highest and lowest values of firmness were noted for the fresh fig fruits and the samples from the last day of storage respectively. The decrease in fruit firmness was mainly due to ripening during storage period [21]. Similar losses in firmness due to ripening have been reported in six melon cultivars during storage [22].

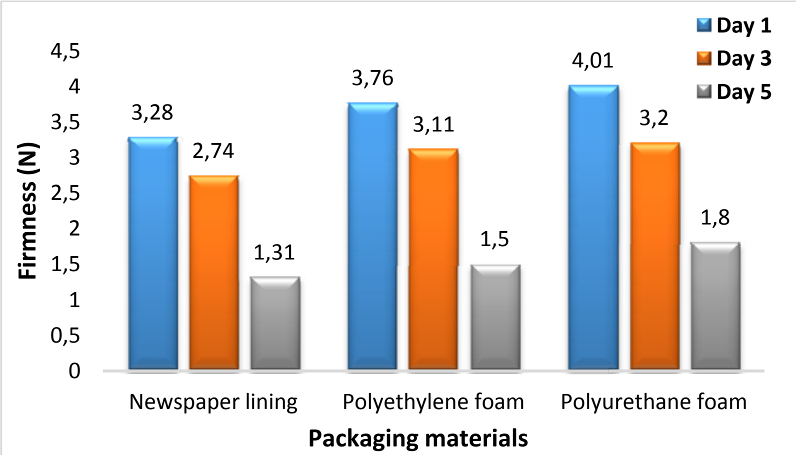

Figure 2. Effect of transportation on firmness of fresh fig fruits

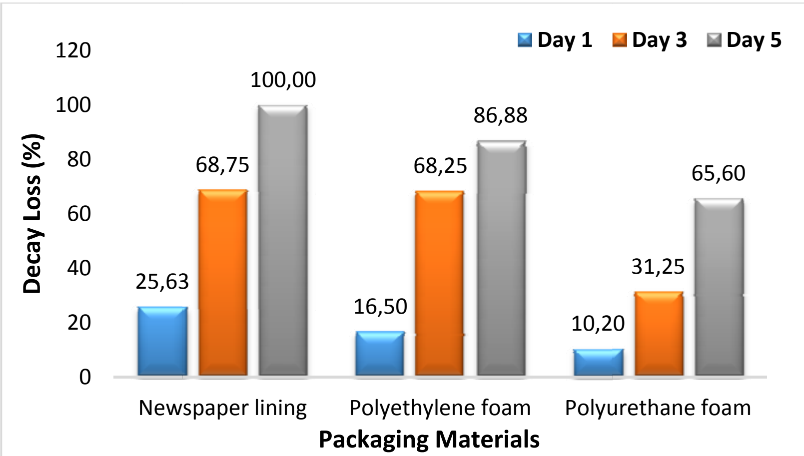

Figure 3. Effect of transportation on decay loss of fresh fig fruits.

The decay loss of fresh fig fruits (Tab. 1) during storage (after transportation) was high in *CFB* box with newspaper lining. Minimum decay loss (Fig. 3) was observed in the fruits packed and transported in *CFB* box with polyurethane foam sheet. During transportation, chances of occurrence of mechanical damage may be higher as the fruits are highly perishable with thin skin and are highly pulpy. Fig fruits are subjected to various types of mechanical forces during transportation [2]. Fig fruits are affected by various post-harvest diseases caused by *Alternaria alternate, Botrytis cinerea, Rhizopus* *stolonifer, Fusarium flocciferum and Cladosorium herbarum* [23]. Hence decay loss is found to be maximum during storage. For the initial days, per cent decay loss was maximum for the fruits packed in *CFB* box with newspaper lining than other packaging materials. On the third day of storage, maximum per cent decay loss was observed for the samples stored in *CFB* box with newspaper lining (68.75 %) fallowed by the fruits packed in *CFB* box with polyurethane foam (68.25 %). The minimum maximum per cent decay loss was observed for the samples stored in *CFB* box with polyethylene foam.

CONCLUSION

Study showed that the transportation packaging materials have significant difference on the transportation losses of fresh fig fruits. More damaged fruits (samples from control packaging material) showed maximum loss in weight and decay loss than less damaged (samples from spongy packaging material) fruits. Packaging materials which having cushioning property protected the fruits from vibration damage.

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STUDIJA MOGUĆNOSTI SMANJENJA GUBITAKA PRILIKOM TRANSPORTA SVEŽE SMOKVE (*Ficus carica* L.)

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Sažetak: U ovoj studiji su utvrđeni gubici koji nastaju prilikom pakovanja, transporta i skladištenja svežih smokvi (*Ficus Caria L.*) Rezultati studije će pomoći farmerima i dizajnerima materijala za pakovanje prilikom odabira odgovarajućeg načina pakovanja kako bi umanjili gubitke u transport. Sveže urbani plodovi smokve se neoštećeni pakuju u *CFB* kutije, u pakovanjima po 10 kg, pri čemu se unutar pakkovanja odvajajau listovima papira, polietilenskom ili poliuretanskom penom. Pakovano voće se potom transportuje u proseku 500 km do odredišta. Na odredištu se plodovi smokve ispituju, pri čemu se obraća pažnja na gubitak u težini, rastvorljivosti suve materije, čvrstoći i kaliranju proizvoda na sobnoj temperaturi. Rezultati ukazuju na to da količina oštećenih plodova bitno zavisi od vrste materijala pakovanja. Oštećenje plodova pakovanih u *CFB* kutije i razdvajanaih papirom je najveće. Plodovi pakovani u poliuretanskoj peni su u čvršći sa sporijim povećanjam *TSS* vrednosti. Rezultati pokazuju da su minimalno oštećeni proizvodi pakovani u *CFB* kutije sa poliuretanom u poređenju sa ostalim načinima pakovanja. Takođe, najmanje su kalirali proizvodi upakovani u *CFB* kutije sa poliuretanom.

Ključne reči: *smokva, materijal pakovanja, transport, gubici*

Prijavljen: *Submitted*:	16.07.2014.
Ispravljen: *Revised*:	17.03.2015.
Prihvaćen: *Accepted*:	18.03.2015.

Univerzitet u Beogradu
Poljoprivredni fakultet
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Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 61 – 71

University of Belgrade
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Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No. 1, 2015.
pp: 61 – 71

UDK: 66.069.832

Originalni naučni rad
Original scientific paper

COMPARATIVE EVALUATION OF SPRAYING TECHNOLOGY IN COTTON BELT OF PUNJAB (INDIA)

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Abstract: With advancement of spray technology and sprayers used on farmer's field will vary significantly from each sprayer in terms of droplet size which ultimately determines its efficacy. Therefore, it is required to standardize and validate the efficient spray technology for enhancing the effectiveness of pesticides in cotton. For tractor operated gun sprayer, the field capacity was found higher due to its large coverage area around covering six to seven rows during one pass on one side i.e. 5.4 to 6.3 m. The operator speed was found to be around 1-1.6 $km \cdot h^{-1}$ and VMD, NMD and UC were found to be 125.71 μm, 33.91 μm, 3.73 respectively. Lesser droplets reach the lower side of the upper leaves where usually the white flies reside.

The $cost \cdot h^{-1}$ for electrostatic sprayer may be high but the deposition efficiency and also the spatial distribution of deposited droplets throughout the plant canopy, particularly under plant leaves application where pests usually hide and reside was found maximum. Thus results in better bio-efficacy. The droplet sizes i.e. VMD, NMD and UC were found to be 52.66 μm, 21.79 μm and 2.54 respectively. Tractor mounted boom sprayer is a recommended technology and showed best results in terms of uniformity, droplet sizes, bio efficacy and high field capacity having VMD, NMD and UC of 124.12, 43.94 and 2.75 respectively. Battery operated knapsack sprayer have VMD, NMD and UC of 137.80μm, 37.01μm and 3.58 respectively but its field capacity was found to be least.

Key words: *Tractor operator gun sprayer, electrostatic sprayer, boom sprayer, knapsack sprayer, droplet size, uniformity coefficient*

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INTRODUCTION

Cotton popularly known as 'white gold' is the main kharif crop of south-western Punjab which includes Faridkot, Firozepur, Bhatinda, Mansa, Abhor and Mukatsar. The total area under cotton cultivation in Punjab was $5.05 \cdot 10^5$ ha during 2013-14 with total production of $21.0 \cdot 10^5$ bales and yield of 707 $kg \cdot ha^{-1}$ [1]. It is found that about 55% of the total pesticide is being consumed on cotton in India against 5% of total cultivable land accounting for 40% of total production costs. This fact signifies the impact of insect pests and the increased agrochemical use in cotton production. Better management is required for realizing better cotton yields which can be achieved by effective spraying and improved application methods. In order to attain uniform deposition and distribution of chemical spray on top, middle, bottom and on the undersides of plant canopy the leaves are of utmost importance for effective control of pests [2]. Farmers in south-west Punjab are using knapsack sprayer which has low application accuracy and require serious safety precautions. Performance depends on skill of operator; manual application often results in an uneven distribution of the pesticide [9]. Earlier the farmers were using tractor operated boom sprayer, but according to their view, either space to be left for moving the tractor or two lines are affected due to less ground clearance of tractor and their yield is affected. The tractor operated boom sprayer consists of a centrifugal pump, a tank, a pressure regulator valve and a boom with nozzles and spray gun fitted on a frame. The sprayer is mounted on the 3 point linkage of the tractor and drive is given through from tractor PTO through asset of gears. Boom height can be adjusted from 10 to 225 cm from ground to suit different crop height. It can cover up to 1200 cm width and has a capacity of about 1.6 $ha \cdot h^{-1}$ at a field speed of 2.5 $km \cdot h^{-1}$.

Recently, the manufactures have launched their own tractor mounted sprayers, fitted with guns having pipe length of 60-100 m very attractive to them. The gun spraying is becoming popular on account of its multipurpose use for cotton, paddy and horticultural crops. Such wide range of coverage of crops from cotton to perennial tall horticultural crops is attained by using the spray guns of different types and specifications. In field, tractor operated gun sprayer required four persons of which two persons are required for handling the pipe, with tractor standing outside the field. In this technique, there may be a chance of over dosage of pesticide which may lead to many problems such as chemical waste and environmental pollution from spray drift. There is no adequate data about its droplet size and coverage etc. Due to its popularity among the farmers the sprayer was evaluated in the field. Electrostatic technique in the agricultural spray is a new technique toward prevention of chemical waste and environmental pollution [5] support the hypothesis that air-assisted electrostatic spray application can be utilized to reduce the quantity of the pesticide active ingredient dispensed into a given crop canopy as compared to conventional high volume hydraulic spraying. It not only improves the deposition efficiency but also the spatial distribution of deposited droplets throughout the plant canopy, particularly under leaf application where pests usually hide and reside, hence increasing the bio-efficacy [6]. For the above said reasons, electrostatic spraying technology has been a concern in research and development for beneficial agricultural applications [4][7]. The quality of spraying machine work is affected by several technological, technical and climatic factors, the most important of which include the type of sprayer, choice of nozzles, appropriate spray parameters, temperature and humidity as well as the instructions of plant protection producer [3]. A comparison study of the conventional and adapted sprayer showed that 37% of the pesticide used was saved using the adapted sprayer whereby the efficacy of the treatments was identical. Pesticide residues on the soil between the fruit trees were negligible pointing to efficient environmental protection [10].Therefore, it is required to standardize and validate the efficient spray technology for enhancing the effectiveness of pesticides with most commonly used sprayers in cotton. The present study was undertaken in the cotton belt of south – west Punjab to evaluate the spraying technology of tractor operated gun type sprayer used by the farmers along with the recommended technology of battery operated knapsack sprayer, boom type sprayer and electrostatic sprayer (new technology in India) under field conditions and to determine the comparative performance of their spraying based on range of droplet size, droplet density and volume of spray deposition using droplet analyzer, bio-efficacy and cost economics were compared.

MATERIAL AND METHODS

The experiments were conducted out at farmer's field Village Khepawalli, District Abhor, Punjab located at 30.137°N latitude and 74.20°E longitude in the month of August and September, 2013. Four sprayers were selected for the experiments i.e. Battery operated Knapsack, boom type, tractor operated gun type and electrostatic sprayers. An Electrostatic sprayer was procured from department of farm machinery and power engineering, PAU, Ludhiana for evaluation at farmer's field. The details specifications of the sprayers are given in Tab. 1. The sprayers were evaluated on an area of 1.2 ha for the selected location. The plot selected was divided into three parts for each sprayer and replications were done. The plot size for each replication was 60 x 20 m. Observations like (*VMD*, *NMD*), uniformity coefficient, droplet density and no. of white flies were taken for evaluating four sprayers. Parameters like wind velocity (km·h^{-1}), temperature (°C), field capacity (ha·h^{-1}), speed of operation (km·h^{-1}) and economics of the four technologies were also recorded / calculated.

Table 1. Specification of the sprayers

Specifications	*Gun*	*Knapsack*	*Electrostatic*	*Boom Type*
Tank capacity (l)	*500*	*15*	*15*	*500*
Power source	*Above 35 HP*	*Manual*	*Manual*	*Above 35 HP*
Operating pressure (kg·cm^{-2})	*10-25*	*3.5-4.5*	*4.2-4.9*	*15-25*
Hose pipe length (m)	*60-100*	*-*	*30*	*-*
No of nozzles	*1*	*1*	*Single/twin*	*16*
Types of nozzle	*Gun*	*Hollow cone*	*Hollow cone with electrode at the tip*	*Hollow cone*
Cost	*35.000-55.000*	*2.500-5.000*	*40.000*	*30.000*

Measurements of droplet size, droplet density and uniformity coefficient

For spray deposition, plants were randomly selected in the field, water sensitive paper strips of size 7.5 x 2.5 cm were placed on the selected plants and divided into 5 portions viz. upper, upper lower, middle, lower canopy and ground surface. The sprayed strips were further analyzed in the laboratory with a droplet analyzer with software installed on computer called as 'USB Digital Scale'. Droplet analyzer consists of microscope, CCD camera, PC and a monitor to control the analyzed picture (The numbers of droplets were noted under each classified range of intervals of 50 microns up to 500 microns [3]. Using the number of droplets and diameter of the droplet in the particular size range graphs were plotted between actual diameter and cumulative percentage of volume; the droplet size at which cumulative percentage of volume contributed reached 50 percent was taken as the Volume Median Diameter (*VMD*) of the sprayed particles and the droplet size at which cumulative percentage number of droplets reached 50 percent was taken as the Number Median Diameter (*NMD*) of the sprayed particles. Uniformity coefficient (*UC*) was calculated by dividing *VMD* by *NMD*. The number of drops in one square centimeter area of glossy paper was obtained on each card and termed as droplet density [8].

Bio-efficacy

For calculation of bio-efficacy in the field, number of pests in the field was counted from 10 randomly selected plants. The pests were counted from a total of 3 leaves of a plant i.e. upper and lower side was recorded before and after the spray. The pest count was further recorded on 1st, 3rd 7th and 10th day after spraying. The difference of number of pests before and after the spray was noted to calculate the percentage reduction of pests. The insecticide used was solution with a recommended dose of 600 ml·acre^{-1}.

Statistical analysis

The results obtained during experiment were statistically analyzed by software SAS 9.3 for verifying their significance of relationship.

RESULTS AND DISCUSSION

This section presents the analysis and interpretation of experimental results obtained during the course of study; relationships between independent variables and dependent variables, shown in table 2-4.

Determination of droplet size and uniformity coefficient

The average volume median diameter (*VMD*) and average number median diameter (*NMD*) was 125.71 μm, 33.91 μm respectively for gun type sprayer. For battery operated knapsack sprayer, the average volume median diameter (*VMD*) and average number median diameter (*NMD*) was 137.80 μm 37.01 μm respectively. Average uniformity coefficient was found to be 3.73 and 3.58 for gun and knapsack sprayers respectively.

While for boom sprayer, the average volume median diameter (*VMD*) and average number median diameter (*NMD*) was 124.12 µm, 43.94 µm respectively with an average uniformity co-efficient of 2.75. For electrostatic average the volume median diameter (*VMD*) was 52.66 µm, and average *NMD* was 21.79 µm. Average uniformity coefficient was 2.54. From table 2 it was cited that both knapsack and gun sprayer gives highest volume median diameter (*VMD*) as compared to other two sprayers. It was also observed that the droplets are more uniform in case of gun sprayer. Tractor mounted boom sprayer also showed uniformity over droplets size as compared to other sprayers as it is not affected by operator's performance. The *VMD* for electrostatic sprayer was the least, due to high air pressure and resisted passage of nozzle the liquid atomized into smaller sizes. This is a main cause for its uniformity coefficient and gives more uniform size particles. In case of gun and knapsack the spraying fully depend upon operator's uniformity and speed of operation. Nozzle orifice diameter and pressure are also the major factors which played a vital role in the uniformity of droplets.

Table 2. Droplet size, µm (VMD, NMD & UC)

S.NO.	Type of sprayer	LS Mean VMD	LS Mean NMD	LS Mean UC
1.	Gun Type	125.71	33.91	3.73
2.	Knapsack(battery operated)	137.80	37.01	3.58
3.	Electrostatic	52.66	21.79	2.54
4.	Boom sprayer	124.12	43.94	2.75

Analysis of variance of volume median diameter (*VMD*)

Tab. 3 shows that the replication was non-significant at 5 per cent level of significance but the individual effect of sprayer for *VMD* was highly significant at 1 % level of significance while effect of place was found to be significant at 7% level of significance. Whereas the combined effect of place and sprayer was found non-significant at 5 % level of significance. It was also indicated that the overall F test is significant at 5% level indicating that the model as a whole accounts for a significant portion of the variability in the dependent variable. The F values indicate that the *VMD* can be varied and dependent on the type of sprayer used and different places of the plant.

Table 3. Analysis of variance of VMD on different sprayers and places

Source	DF	Mean Square	F Value	Pr > F
Replication	2	500.33282	0.26	0.7707
Place	4	11519.01019	6.04	0.0007
Sprayer	3	22533.74381	11.81	<0.0001
Place*sprayer	12	2802.66008	1.47	0.1789
Model	21	7062.37420	3.70	0.0002
Error	38	1907.66870		

**Places indicate water sensitive paper positions i.e. top upper, top lower side, middle, lower and ground.*

Analysis of variance of number mean diameter (*NMD*)

The analysis of variance (Tab. 4) indicates that neither the replication nor the combined effect of place and sprayer are significant to the variation of *NMD*. But it was found the individual effect of sprayer for *NMD* as independent parameter was significant at 6 % level of significance. The overall *F* test is non significant at 5% level indicating that indicating that the model as a whole doesn't accounts for a significant portion of the change with the dependent variable at 5% level.

Table 4. Analysis of variance of NMD on different sprayers and places

Source	*DF*	*Mean Square*	*F Value*	*Pr > F*
Replication	*2*	*237.546402*	*0.48*	*0.6200*
Place	*4*	*346.741684*	*0.71*	*0.5924*
Sprayer	*3*	*1283.827202*	*2.62*	*0.0650*
*Place*sprayer*	*12*	*583.045486*	*1.19*	*0.3260*
Model	*21*	*605.242240*	*1.23*	*0.2800*
Error	*38*	*490.700210*		

Analysis of variance of uniformity co-efficient

The (Tab. 5) indicates that combined effect of sprayer and place was found to be non-significant at 5 per cent level of significance, except effect of place as an individual parameter found to be significant at 5 % level. The overall *F* test for the model was found to be non- significant at 5% level indicating that the model as a whole accounts for a non-significant portion of the change with the dependent variable.

Table 5. Analysis of variance of uniformity coefficient on different sprayers and places

Source	*DF*	*Mean Square*	*F Value*	*Pr > F*
Replication	*2*	*0.41037500*	*0.17*	*0.8428*
Place	*4*	*6.48088917*	*2.71*	*0.0442*
Sprayer	*3*	*5.26907111*	*2.21*	*0.1033*
*Place*sprayer*	*12*	*1.90811139*	*0.80*	*0.6493*
Model	*21*	*3.1166122*	*1.30*	*0.2326*
Error	*38*	*2.3891680*		

Droplet density

Three replications were compared between the sprayers in the field and LS mean from SAS 9.3 software was calculated, it was found that for Gun sprayer the droplet density was 173 at top upper portion of the leaf while droplet density was 56 on the under side of the leaves. The middle portion of the leaves was observed to have highest density with 364 drops. It was observed the no. of drops at the lower and ground portion was found to be 172 and 164 respectively. The non-uniformity may be due to operator's uneven method of the spraying. The droplet density for knapsack was found to be 106 on top portion while 10 droplets were found on upper lower side and droplet density were seen to vary from 97-124 on lower and ground portion of the leaf. Due to air assisted spray and electrically charged particles complete and uniform coverage of droplets were seen for electrostatic sprayer on the total plant canopy. For top portion the droplet density was found to be 336, on the top lower portion 241 droplets were found while on lower and ground portion of the leaf 96 and 70 drops were observed respectively. The boom sprayer showed a droplet density of 239 on top portion of the leaf while 37 droplets were observed for top lower portion. While the middle, lower and ground portion droplet density varied from 159, 96 and 70 respectively.

Table 6. Droplet density (droplets·cm^{-2})

S. No.	Type of sprayer	Position of water sensitive paper on the plant				
		Top upper portion	Top lower	Middle	Lower	Ground
1	Tractor operated gun type sprayer	173	56	364	172	164
2	Knapsack (battery operated)	16	140	83	124	97
3	Electrostatic sprayer	336	241	824	380	521
4	Boom sprayer	239	37	159	96	70

Bio-efficacy results

Tab. 7 revealed that different treatments did not differ significantly before spray. After three days of spray, electrostatic spray was found to be more effective in reducing the whitefly population to 8.58 followed by tractor mounted boom sprayer, tractor operated gun sprayer and knapsack spray 13.28, 16.08 and 18.97 per three leaves, respectively. However, all the treatments were better than control. After 7 DAS whitefly population was significantly lower in Electrostatic spray, Gun spray and tractor mounted boom sprayer (5.45, 5.78 and 6.44 per three leaves) followed by Knapsack spray (12.67 per three leaves). After 10 DAS, whitefly population was significantly lower in electrostatic spray, gun sprayer and tractor mounted sprayer (5.67, 6.33 and 7.00 per three leaves) followed by Knapsack spray (13.22 per three leaves). However, all the treatments were better than control.

Table 7. Efficacy of different treatment against whitefly (Bemisia tabacion) on BT cotton

Treatment	Pre-treatment	3 DAS*	7 DAS	10 DAS
Tractor operated gun type sprayer	35.11	16.08 (4.12)**	5.78 (2.60)	6.33 (2.70)
Boom sprayer	37.33	13.28 (3.78)	6.44 (2.72)	7.00 (2.82)
Knapsack (battery operated)	37.44	18.97 (4.46)	12.67 (3.69)	13.22 (3.77)
Electrostatic sprayer	34.53	8.58 (3.09)	5.45 (2.54)	5.67 (2.58)
Control	35.11	39.11 (6.33)	41.67 (6.53)	46.78 (6.90)
CD (p=0.05)	NS	(0.47)	(0.29)	(0.37)

** Days after spraying, **Square root transformation*

Cost of spraying

The cost of spraying were compared between the four sprayers and it was found that the total cost·h^{-1} including fixed and variable, for gun sprayer was around Rs.381/- including tractor cost of Rs. 302/-. The field capacity was found to be around 0.8 ha·h^{-1}. For electrostatic sprayer, total cost·h^{-1} was found to be Rs.323/- with a field capacity of 0.1 ha·h^{-1}, while knapsack on the other hand had minimum cost of Rs. 27.5 per hour due to its labor requirement factor and have a field capacity of 0.08 ha·h^{-1}. For boom sprayer the total cost·ha^{-1} was 330/- including tractor cost of Rs. 302/- with field capacity of 1.6 ha·h^{-1}. While, the spraying cost·ha^{-1} for gun type sprayer, battery operated knapsack sprayer, electrostatic sprayer, and tractor operated boom sprayer were found to be Rs. 476.0, 344.0, 3233, 208.0 respectively (shown in Fig. 1).

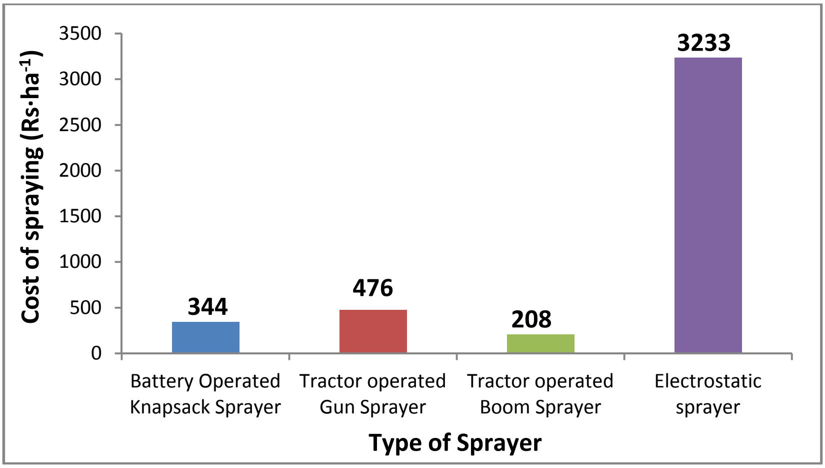

Figure 1. Cost of spraying of different sprayers

The cost·ha^{-1} for tractor operated boom sprayer was found to be least because of its high field capacity. For tractor operated gun sprayer, four persons are required for spraying operation in the field. Out of four, two persons are required for handling the discharge pipe, one for spraying with gun and one near the tractor. While three persons were employed in case of electrostatic sprayer, of which two persons are required for handling the discharge pipe and spraying with gun and one near the engine for its movement in the field. For knapsack sprayer, only single person is required for the spraying operation, but it is time consuming, tedious and does not provide effective coverage.

CONCLUSIONS

From the above parameters like quality, field capacity, cost economics and bio-efficacy results it can be inferred that the *VMD* and *NMD* of different sprayers vary significantly showing the differences in their droplet sizes. The uniformity coefficient was found to be non significant for different sprayers. For tractor operated gun sprayer, the field capacity was found higher due to its large coverage area around covering six to seven rows during one pass on one side i.e. 5.4 to 6.3 m. The operator speed was found to be around 1-1.6 $km \cdot h^{-1}$, but the quality results showed that the *VMD* and *NMD* were within the range. The droplet density on the lower side of the leaf was found to be less as compared to electrostatic sprayer where most of the white flies reside. Bio efficacy is found to be under control. The high discharge and ergonomically method of spraying are the major disadvantages with this technique. The battery operated knapsack sprayer had droplet size within the recommended range having minimum field capacity and time consuming. Bio efficacy was found to be lower among other sprayers but cost of spraying was found least. Tractor mounted boom sprayer was a recommended technology and showed best results in terms of uniformity, droplet sizes, bio efficacy and high field capacity. For electrostatic sprayer, higher droplet density was observed and cost of spraying per ha was highest but its deposition efficiency and bio efficacy was best among the four sprayers. The spatial distribution of deposited droplets throughout the plant canopy, particularly under leaf application where white flies usually hide and reside was found to be highest i.e. 241 $droplets \cdot cm^{-2}$.

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KOMPARATIVNO ISPITIVANJE TEHNOLOGIJE PRSKANJA U POJASU PAMUKA U PENDŽABU (INDIA)

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Sažetak: Sa unapređenjem tehnologije prskanja i prskalica koje farmeri koriste na terenu, veličina kapljice, koja odlučujuće određuje efikasnost rada mašine, značajno se razlikuje kod svake prskalice. Zato je potrebno da se standardizuju i procene efikasne tehnologije prskanja za unapređenje efikasnosti primena pesticida u pamuku. Kod traktorskog rasprskivača utvrđen je viši poljski kapacitet zbog velike oblasti pokrivanja od šest do sedam redova u jednom prohodu na jednoj strani, odnosno 5.4 do 6.3 m. Radna brzina je iznosila 1-1.6 $km \cdot h^{-1}$, a *VMD*, *NMD* i *UC* su iznosili 125.71 µm, 33.91 µm i 3.73, redom. Manje kapljice stigle su do naličja gornjih listova gde obično žive bele muve.

Troškovi na čas rada elektrostatičke prskalice mogu biti visoki, ali efikasnost taloženja i prostorna distribucija deponovanih kapljica po celoh biljci, posebno ispod lišća gde se štetočine obično kriju, bili su maksimalni. Ovo dovodi i do bolje bio-efikasnosti. Veličine kapljica, odnosno *VMD, NMD* i *UC* iznosili su 52.66 µm, 21.79 µm i 2.54, redom. Nošena traktorska prskalica se preporučuje jer je pokazala najbolje rezultate u smislu ujednačenosti, veličina kapljica, bio-efikasnosti i visokog poljskog kapaciteta, a *VMD*, *NMD* i *UC* su iznosili 124.12, 43.94 i 2.75, redom. Leđna prskalica sa baterijskim napajanjem je imala *VMD*, *NMD* i *UC* od 137.80 µm, 37.01 µm i 3.58, redom, ali je njen poljski kapacitet bio najmanji.

Ključne reči: *traktorski rasprskivač, elektrostatički rasprskivač, prskalica, leđna prskalica, dimenzije kapljice, koeficijent ujednačenosti*

Prijavljen: *Submitted*:	11.07.2014.
Ispravljen: *Revised*:	26.02.2015.
Prihvaćen: *Accepted*:	07.03.2015.

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 71 – 83

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No. 1, 2015.
pp: 71 – 83

UDK: 551.583

Originalni naučni rad
Original scientific paper

ASSESSING HYDROLOGICAL DROUGHT CHARACTERTICS: A CASE STUDY IN A SUB BASIN OF TAMIL NADU, INDIA

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Abstract: Assessment of hydrological drought and evaluation of drought characteristics provide useful information for sustainable water resources planning and management in a river basin. In the present study, streamflow drought index (*SDI*) was used to assess the hydrological drought characteristics in the Parambikulam-Aliyar basin of Tamil Nadu, India by considering streamflow volume as an indicator of drought severity. The temporal behavior of hydrological droughts were analyzed initially and then, frequency of annual drought severity and recurrence patterns of severe drought events was assessed. The temporal analysis of the *SDI* values indicated that moderate, severe and extreme droughts are common in the Aliyar sub basin and suggested that the basin suffered severe drought during the 1970s, 1980s and 2000s especially in 1972-74, 1982-85, 1987-88 and 2002-04. January followed by June are the months during which hydrological drought occurs most frequently. Frequency analysis of drought severity indicated that the drought that occurred in the 1970s, 1980s and 2000s has an associated return period of about 80 to 100 years. The results of this study can be used as guide to develop drought preparedness plans and formulate mitigation measures within the basin.

Key words: *streamflow, SDI, drought severity, return period*

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This research work was financially supported by the Council of Scientific and Industrial Research (CSIR), Human Resource Development Group (Extra Mural Research Division), New Delhi under research fellowship program.

INTRODUCTION

Drought is a natural phenomenon that has significant damages both in human lives and economic losses. Drought is a normal, recurring feature of climate; it occurs in almost all climatic regimes. Drought is mostly related to scarcity of water for a period of time, such as a season or a year. Drought produces an impression of water scarcity resulted due to insufficient rainfall, high evapo-transpiration, and over-exploitation of water resources or combination of these parameters [1]. Drought adversely affects various sectors of human society, e.g. agriculture, hydropower generation, water supply, industry.

Droughts are defined based on the variables used for assessing different types of drought. The prime variable for the meteorological drought is precipitation/rainfall, whereas for the hydrological drought it is either river runoff/streamflow or reservoir levels and/or groundwater levels. For agricultural drought, the main variables are soil moisture and/or consumptive use. Historical data of these variables can be used to assess the respective types of drought. This study focuses on the hydrological drought which is defined as period during which streamflows are inadequate to supply established uses under a given water management system.

Droughts are usually assessed and monitored by drought indices. A drought index is typically a single value used for indicating the severity of a drought and is far more useful than raw data in understanding the drought conditions over an area. Numerous specialized indices have been proposed so far, to assess the various types of drought, some of them are region specific [2]. These indices can be used to assist water managers to assess droughts effectively and forecast future drought conditions, which will allow them to plan ahead the water management activities during droughts. This study uses Streamflow Drought Index (*SDI*) for assessing hydrological drought characteristics.

Drought is a frequent phenomenon in India. Out of 329 Million ha of total geographical area in India about 107 Million ha of lands are subjected to different degrees of water stress and drought conditions [3]. More than 100 districts spread over 13 states of India have been identified as drought prone districts, out of these, about 8 districts falls in the Tamil Nadu [4]. The western region of Tamil Nadu which lies in semi arid region have suffered with severe droughts at many times in the past. Due to the growth of population and expansion of agricultural and industrial sectors, the demand for water has increased manifold and even water scarcity has been occurring almost every year. Global climate change and increasing water demand have further intensified the droughts with higher peaks and severity levels. Assessment of droughts is of primary importance for water resources planning and management. This requires understanding historical droughts in the region. The objectives of this study are to analyze the temporal variations of hydrological drought and assess the frequency of drought severity. Aliyar sub basin was selected as study area in the Parambikulam-Aliyar basin spread over drought prone districts of Coimbatore and Tiruppur, Tamil Nadu.

MATERIALS AND METHODS

Study area and data used: Parambikulam-Aliyar basin (referred as *PAP* basin) is located in the south western part of the Peninsular India covering areas in Kerala and

Tamil Nadu States (Fig. 1). The basin is drained by eight west flowing rivers viz. Valaiyar, Koduvadiaru, Uppar, Aliyar and Palar (tributaries of Bharathapuzha river) and Parambikulam, Solaiyar and Nirar (tributaries of Chalakudi river). They are grouped into 4 sub basins such as Valaiyar, Aliyar, Palar, and Solaiyar sub basin and spread over an area of 2388.72 km^2. One third of the basin area (822.73 km^2) is covered with hills and dense forest cover. The water is diverted from west flowing rivers to east by constructing weirs, seven storage reservoirs, tunnels, open channels and contour canal etc. to irrigate the drought prone areas of Coimbatore, Tiruppur districts. This basin area lies (except the Ayacut area) within the coordinates of North latitude between 10° 10' 00" to 10°57'20" and East longitudes 76°43'00" to 77° 12'30". Parambikulam-Aliyar river basin has an undulating topography. The *PAP* basin has a large geographic variation and it reflected in the rainfall over the basin. More rainfall can be observed in the southern parts of the basin (Solaiyar sub basin). When it comes to the middle (Aliyar and Palar sub basin) and northern parts of the basin (Valaiyar sub basin), the rainfall decreases. Mean annual areal rainfall over the whole *PAP* basin is about 1410 mm and it is distributed unevenly in space and time.

This study investigates the hydrological drought in the Aliyar sub basin. The Aliyar River has its source in the Anamalai Hills. It flows in a north-westerly direction for about 37 km in Tamil Nadu and enters into Kerala and finally confluence in Bharathapuzha. Aliyar reservoir is one among the main component in PAP with a surface area of 6.50 km^2 and formed in the plains across the river with a gross storage capacity of 109.42 *MCM*. The catchment area at the Aliyar Dam is 196.83 km^2. Apart from its own catchment, water can be diverted to this reservoir through the Aliyar Feeder canal and the Contour canal from the Parambikulam group of reservoirs. Total area of sub basin is 574.75 km^2 and command area of 20,536 ha that covers Pollachi (N), Pollachi (S) and Anamalai block of Coimbatore district. Crops grown in this sub basin area are Coconut, Sugarcane, Banana, Sapota, Mango, Fodder, besides annual crops, such as Paddy, Groundnut, Cotton, Vegetables, Pulses, Fodder, Tomato, Gaurds, Maize as I crop, and Paddy and Groundnut as II crop.

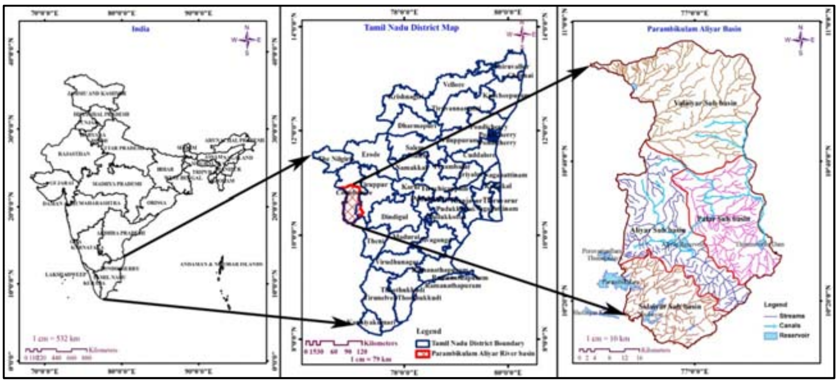


Figure 1. Location of Parambikulam-Aliyar of Tamil Nadu in India

Aliyar sub basin was considered as the study area in this research, since the management of water resources in this basin has great importance in terms of a wider range of water uses as well as downstream user requirements and environmental flows. However, due to frequent droughts and increasing water demand in recent years, pressure on the water resources management activities have increased within the basin.

This study employs streamflow as hydrological drought indicator. Monthly streamflow data (inflows to the reservoir) at the Aliyar reservoir of Aliyar sub basin was obtained from the office of the Superintending Engineer, Parambikulam Aliyar Basin Circle, Water resource Organization, Public Works Department, Pollachi, Coimbatore. Data used to study hydrological drought cover the period from 1970-71 to 2010-11 for Aliyar sub basin. In this study July to June is considered as a hydrological year.

The methodology presented for analyzing the hydrological drought in this study and applied to Aliyar sub basin consisted of the calculation of the *SDI* values using the streamflow volume, analysis of the temporal characteristics of droughts (Occurrence of drought categories and assessment of drought parameters) and development of drought Severity-Frequency curves (*SF* curves) for annual droughts.

Use of SDI for drought analysis: The *SDI* used in this study is statistically similar to the most commonly used Standardized Precipitation Index (*SPI*) developed by McKee *et al.* [5] for meteorological drought analysis. Other hydrological drought indices such as Palmer Hydrological Drought Index (*PHDI*), or Surface Water Supply Index (*SWSI*) are, in general, data demanding and computationally intensive, where as *SDI* requires minimum input, easy to calculate and keeps the simplicity and effectiveness of *SPI*. The *SDI* for a given period is defined as the difference of streamflow from mean divided to standard deviation [6] as follows:

$$SDI_{i,j} = \frac{Q_{i,j} - \bar{Q}_j}{S_j} \tag{1}$$

Where:

$Q_{j,i}$ [mcf] - streamflow volume for a particular month j (Jan.- Dec.) of the i^{th} hydrological year,

$\overline{Q_J}$ [mcf] - mean streamflow volumes for a particular month j (Jan.- Dec.),

S_j [mcf] - standard deviation of streamflow volumes for a particular month j.

The hydrological drought index of Eq. 1 is identical to the standardised streamflow volume. Generally, for small basins, streamflow may possess a skewed probability distribution which can well be approximated by the family of the Gamma distribution functions. The distribution is then transformed into normal [7]. In this study two parameter log normal distribution was used for which the normalisation is simple: it suffices taking natural logarithms of streamflow. The SDI index is defined as:

$$SDI_{i,j} = \frac{y_{i,j} - \bar{y}_j}{S_{y,j}} \tag{2}$$

Where $y_{i,k} = ln(Q_{i,k})$ $i=1,2,..$ *(year)*; $j=1, 2, 3..12$*(month)* are the natural logarithms of cumulative streamflow volume with mean $\overline{y_J}$ and standard deviation $S_{y,j}$ as these statistics are estimated over a long period of time.

Based on *SDI* values computed for Aliyar sub basin, categories of hydrological drought are classified which are identical to those used in the meteorological drought indices *SPI*. Four drought categories are considered which are denoted by *D1* (mild drought), *D2* (moderate drought), *D3* (Severe drought) and *D4* (extreme drought) and are defined through the criteria of Tab. 1.

Table 1. Drought classification by SDI value and corresponding probabilities

Sl.No.	*Drought Category*		*SDI*	*Probability (%)*
1	*D1*	*Mild drought*	*0 to -0.99*	*34.1*
2	*D2*	*Moderate drought*	*-1.00 to -1.49*	*9.2*
3	*D3*	*Severe drought*	*-1.50 to -1.99*	*4.4*
4	*D4*	*Extreme drought*	*≤ -2.00*	*2.3*

Analysis of occurrence of drought: The *SDI* values calculated from the time series of the monthly streamflow volume of the Aliyar sub basin help to assess the temporal variation of hydrological drought and estimate the drought parameters. The calculated monthly SDI values were classified based on drought categories as presented in Tab. 1. The occurrence of drought categories in percentage is computed by taking the ratio of number of drought occurrences under each drought category to the total occurrences of all drought categories in the sub basin [8][9]. Similarly monthly distribution of occurrence of drought categories was calculated.

Assessment of drought properties: The theory of runs as proposed by Yevjevich (1967) [10] is used to determine properties of hydrologic droughts. A run is defined as a part of time series of drought parameter X_t, in which all values are either below or above the selected truncation level of *Xo*; accordingly it is called either a negative run or a positive run (Fig. 2). The truncation level has been defined as the mean over a long period of time. Major components of a hydrologic drought event are [11][12]; Drought duration (D_d) is time period between the initiation (T_i) and termination (T_e) of a drought event expressed in years/months etc. during which a drought parameter is continuously below the truncation level. Drought severity (S_e) indicates a cumulative deficiency of a drought parameter below the truncation level. It is calculated as the sum of negative *SDI* values in dry spells (Between T_i and T_e). Drought intensity (I_e) is the average value of a drought parameter below truncation level. It is measured as the drought severity divided by the duration. Most intense drought is the extreme drought event during the period of water shortage (the highest departure of the *SPI* value from its normal value or peak negative *SDI* value). In this study, drought duration, severity and intensity of extreme drought and most intense drought experienced in Aliyar sub basin was derived from the monthly *SDI* values.

Development of drought Severity-Frequency (*SF*) curves: A method to assess the frequency of worst droughts experienced over the period of analysis with respect to drought severity of a basin is the drought severity-frequency (*SF*) curves. In this paper drought severity-frequency curves was developed similar to severity-areal extent-frequency (*SAF*) curves proposed by Henriques and Santos (1999) [13] and the same procedure adopted by Kim *et al*. (2002) [14]; Loukas and Vasiliasdes (2004) [15]; Mishra and Desai (2005) [3]; Zhang *et al.* (2012) [16]; Manikandan and Tamilmani, (2013) [17]. The areal extent of drought event which is very useful for meteorological drought was not considered for hydrological droughts analysis.

The *SF* curves were developed based on the weighted annual cumulative drought severity and average annual drought severity. The procedure employed in this study for deriving drought severity-frequency (*SF*) curves is: 1) The monthly *SDI* values for each year were calculated; 2) The annual weighted cumulative drought severity was estimated by multiplying the annual sum of negative SDI values in monthly dry spells by the probability of drought occurrence for each year; 3) The probability of annual drought occurrence for each year was estimated by dividing the number of months that have a negative *SDI* value by 12; 4) To find out the best distribution for the frequency analysis, drought severity was tested using different probability distributions; 5) Using the selected probability distribution drought severity was estimated at different return periods; 6) Severity of selected drought years was compared with estimated severity at different return periods. Severe drought years were selected based on least negative quantity of drought severity; 7) Weighted annual cumulative SF curves were developed and repeated the analysis for developing annual average drought severity-frequency curves. In this analysis duration of drought can be considered uniformly for a particular year, avoid intermittence, and the duration of monthly drought event within a particular year is implicitly taken into account [15].

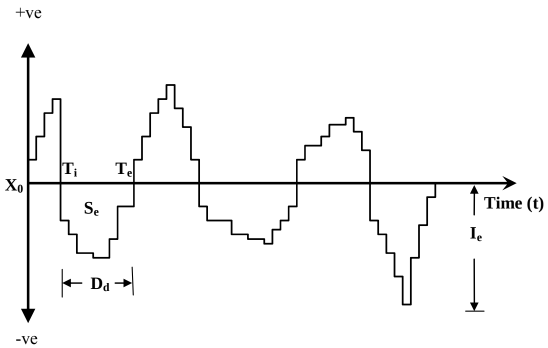


Figure 2. Drought characteristics using run theory for a given threshold level, X_0

The annual average drought severity was estimated by dividing the annual sum of negative SDI values in monthly dry spells for a particular time scale by 12. This analysis estimates the annual drought severity without giving any consideration on the duration of monthly drought event. This means that an extreme drought event that lasts few months may have the equal representation with a long lasting severe and moderate drought event. However, this analysis indicates, on average, how much intense a drought occur in a particular year.

The frequency analysis is the traditional and practical method used in hydrology and meteorology to assess the return period of particular events. Frequency analysis is performed using the selected probability distribution for annual weighted cumulative and annual average drought severity at different return periods. In this study, the annual drought severity has negative values. To be applied before fitting to an available distribution, the negative values of annual drought severity were transformed to positive values in order to represent the extreme condition and to analyze the associated risk of droughts using the exceedance probability.

The commonly used probability distributions viz. Normal, Lognormal, Gamma, and Extreme Value Type I were used to evaluate the best fit probability distribution for annual weighted cumulative and annual average drought severity and tested by non parametric Kolgomorov–Smirnov (*K-S*) test and parametric Chi-Square tests at 5% and 1% significance levels. The annual drought severity X_T to be estimated for a given return period (T) may be represented as the mean μ plus the departure ΔX_T of the variate from mean. The departure may be taken as equal to the product of the standard deviation σ and a frequency factor K_T; that is, $\Delta X_T = K_T\sigma$. The departure ΔX_T and the frequency factor K_T are functions of the return period and type of probability distribution to be used in the analysis [18]. The expected annual drought severity at various return periods 2, 3, 5, 10, 20, 25, 50, 75 and 100 years were worked out by the best fit probability distribution.

RESULTS AND DISCUSSION

Temporal variation of hydrological drought: Time series of monthly streamflow volumes (mcf) of Aliyar sub basin is shown in Fig. 3. The average cumulative streamflow volume was compared to normal cumulative streamflow volume for Aliyar sub basin over the study period for identifying the worst streamflow deficit years. From this analysis, it was found that the Aliyar sub basin experienced streamflow deficits during the period 1970s, 1980s and 2000s. During these three periods the monthly and annual streamflow was considerably below normal. Fig. 4 illustrates the cumulative monthly streamflow volumes for selected deficit years and periods of Aliyar sub basin. The hydrological year of 1972-73, 1973-74, and 1982-83 are the first, second and third driest years in record, respectively for Aliyar sub basin (Fig. 4). The Aliyar sub basin experienced extreme dry periods during 1970s and 1980s. The prolonged and remarkable decrease of monthly and annual streamflow has a significant impact on water resources of the basin. Usually, the dry periods are associated with low rainfall, high temperatures, which lead to higher evapotranspiration rates and dry soils. These parameters inversely affect both the vegetation and the agriculture of the region as well as the available storage of the reservoirs. Severe and extremely dry conditions lead to irrigation cutbacks, overexploitation of groundwater and dramatic losses of crop yields.

The temporal variation of droughts in the Aliyar sub basin were analyzed by analyzing the time series of SDI values computed for the Aliyar sub basin (Fig. 5). The monthly SDI time series shows that the basin experienced frequent droughts for the period of drought analysis and detected several severe and extreme drought events.

Monthly distribution of occurrence of drought categories presented in the Table 2 showed that mild droughts occur most frequently and extreme droughts occur least frequently. The basin experienced frequent droughts for all months of the year. The Aliyar sub basin had experienced 44.51 per cent of occurrence of drought over the period of analysis. It is noted that the basin has experienced severe drought during 1970s, 1980s and 2000s in terms of annual drought severity. Annual drought severity was calculated by summing up the negatives SDI values in dry spells. The years which gives least quantity of drought severity was identified. 1972-74, 1982-85 and 2002-04 are the most severe drought years experienced over the period of analysis. Analysis of occurrence of drought shows that January, June and July are the months during which the *SDI* values most frequently takes the negative *SDI* value and it is followed by February, March and May.

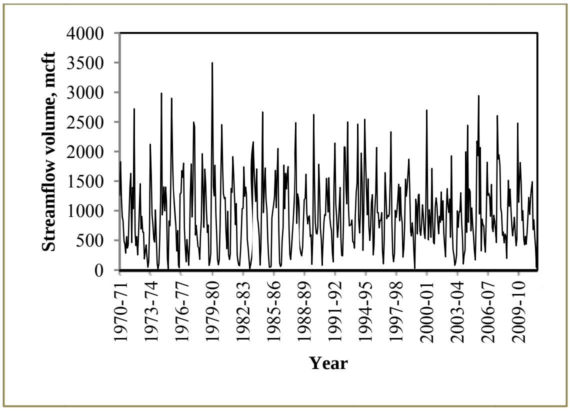


Figure 3. Time series of monthly streamflow volumes of Aliyar sub basin

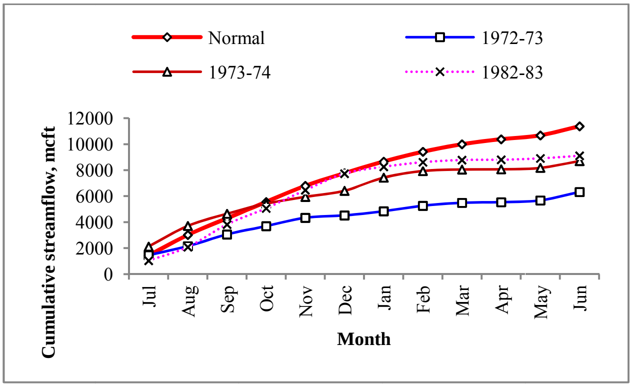


Figure 4. Cumulative monthly streamflow volumes for selected dry years of Aliyar sub basin

Tab. 3 presents the summary of hydrological drought properties derived from the Fig. 5 occurred in the Aliyar sub basin. The number of drought incidences is defined as the number of times drought occurs in the *PAP* basin over the period of analysis i.e number of times the negative *SDI* values continually follows. It is found that the total number of drought months and the number of drought incidences for Aliyar sub basin is 219 and 93 months respectively. Average duration of drought (number of drought months divided by number of drought incidences) calculated in the basin was 2.35 month. The period of longest duration of drought was experienced in 1972/08-1973/06 and its severity (sum of negative SDI values) was -14.47. Intensity (ration of severity and duration) of longest duration and highest severity drought was -1.16. The most intense quantity i.e. minimum negative of SDI values for Aliyar basin was observed in December 1972 (*SDI* = −3.15). It is referred as extreme drought month over the study period.

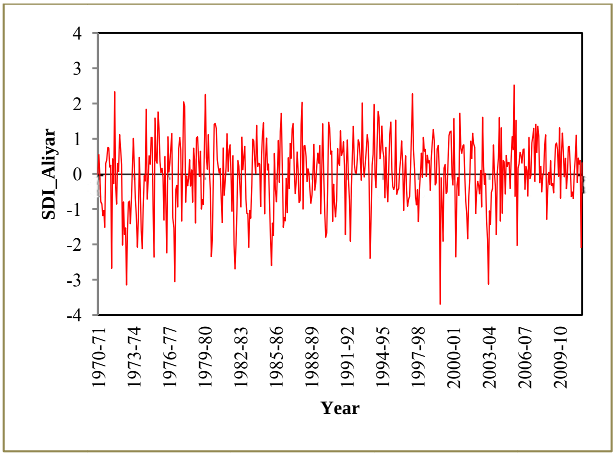


Figure 5. Temporal variation of SDI values in the Aliyar sub basin

Table 2. Monthly distribution of occurrence of drought categories in the Aliyar

Month	D1	D2	D3	D4	Total
January	3.46	0.41	0.00	0.41	4.27
February	2.64	1.22	0.00	0.20	4.07
March	2.64	0.81	0.20	0.20	3.86
April	2.24	0.41	0.61	0.20	3.46
May	2.64	0.41	0.61	0.20	3.86
June	3.25	0.41	0.20	0.41	4.27
July	3.25	0.41	0.20	0.41	4.27
August	2.24	0.41	0.41	0.41	3.46
September	1.83	0.20	1.02	0.20	3.25
October	1.63	0.81	0.00	0.61	3.05
November	1.22	1.22	0.20	0.41	3.05
December	2.44	0.61	0.41	0.20	3.66
Total	29.47	7.32	3.86	3.86	44.51

Table 3. Hydrological drought properties of SDI series for Aliyar sub basin

Sl.No.	Drought properties	Aliyar sub basin
1	No of drought months (<-0)	219
2	No of drought incidence	93
3	Average duration in months	2.35
4	Longest duration of drought (month)	10
5	Period of longest duration	1972/08-1973/06
6	Severity of longest duration	-14.47
7	Drought intensity	-1.45
8	Most intense drought	Dec 1972 (-3.15)

Analysis of frequency of drought severity: The results of Goodness fit test for candidate distributions for weighted and annual drought severity for Aliyar sub basin is presented in Tab. 4. The results as shown in Table 4 indicated that most of the distributions passed the test. The Extreme Value Type I (*EV I*) distribution was selected in this study. This distribution is a special case of the Generalized Extreme Value (*GEV*) distribution with two parameters and its parameter values may be estimated with less uncertainty, as the small sample size is used here. It is also used for the numerous extreme drought studies [3] [14] [15]. For the Extreme Value Type I distribution frequency factor can be expressed as:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + ln\left[ln\left(\frac{T}{T-1}\right)\right]\right\} \tag{3}$$

Frequency factor of Extreme Value Type I distribution was applied in the Eq. 3 and calculated annual drought severity for different return period (*T*).

Table 4. The results of Goodness fit test for candidate distributions for SDI values

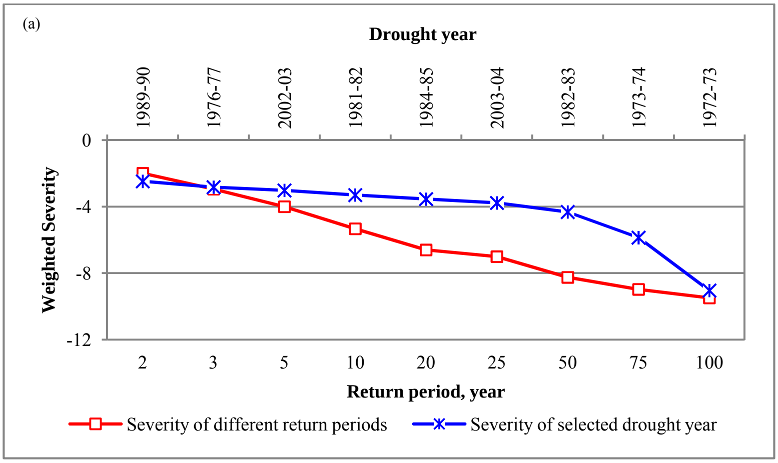
Drought severity	*Weighted Severity*		*Average Severity*	
Goodness of fit Test Distributions	*K-S*	*Chi square*	*K-S*	*Chi square*
Gamma	*0.1232*	*1.528*	*0.0884*	*2.197*
Extreme Value Type I	*0.0811*	*1.517*	*0.0664*	*1.641*
Log-normal	*0.0929*	*2.632*	*0.0947*	*4.289*
Normal	*0.2176*	*13.2*	*0.1674*	*7.805*

Significant level of K-S Test at 1% = 0.26 and 5% = 0.21; Significant level of chi-square test for 4 degrees of freedom at 1% = 13.28 and 5% = 9.48.

Analysis of drought severity – frequency curves: The *SF* curves of annual weighted cumulative drought severity of Aliyar sub basin corresponds to different return periods constructed in this study are presented in Figs. 6a and 6b. The highest weighted annual cumulative drought severity was observed in the year 1972-73 has an associate return period of above 100 years. The drought that occurred in 1989-90 has an associate return period of 2 years (Fig. 6a). The highest annual average severity that observed in the year 1972-73 and the drought that occurred in 2003-04 has an associated return period of 100 years and 2 years respectively (Fig. 6b). The results of this study may provide a scientific basis for decision makers to formulate drought mitigation measures with respect to water resources planning and management.

CONCLUSIONS

This study was focused on analyzing hydrological drought characteristics in the Aliyar sub basin using the streamflow drought index (*SDI*) as an indicator of drought severity. The *SDI* was computed based on the monthly streamflow volume and drought severities were classified into four drought categories. Occurrence of drought categories was estimated and the results revealed that the basin experienced quite frequent moderate, severe and extreme droughts on monthly basis. The results indicated that the basin has experienced prolonged and severe droughts in terms of severity and durations in the 1970s, 1980s and 2000s. In particular, the persistent and prolonged drought of 1972-1974 and 1982-1985, 2002-2004 seriously affected drinking water supply, canal water supply for agricultural irrigation, ground water as well as reduction of inflows to the reservoir. The drought severity - frequency curve constructed in this study are used to find out the return period of drought affected years in terms of their severity. Obtaining drought properties is important for planning and management of water resources system. Moreover, the estimation of return periods associated to severe droughts and probability of occurrence of drought severity can provide useful information in order to improve water systems management and to work out the best possible supply of canal water in the basin and planning drought mitigation measures under drought condition. These studies will be helpful once drought is identified and before it moves to next severity levels, information may be conveyed to other sectors to ensure that they will act timely and effectively to tackle with drought.



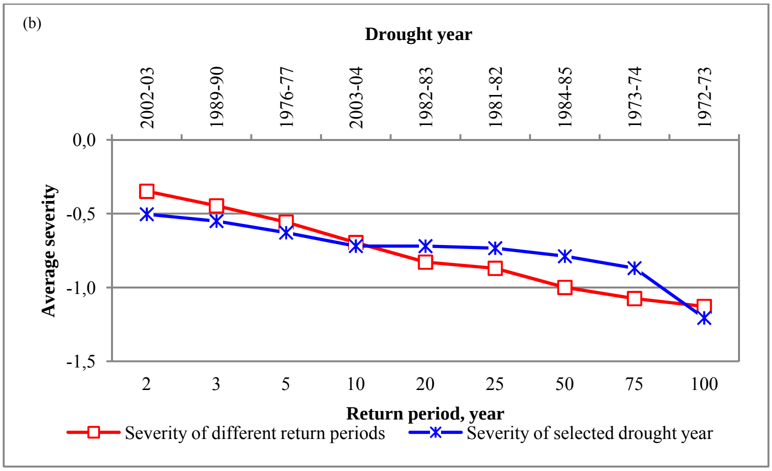


Figure 6. Drought severity-frequency curve for: (a) weighted severity, (b) average severity

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PROCENA HIDROLOŠKIH OSOBINA SUŠE: STUDIJA U OBLASTI BASENA TAMIL NADU U INDIJI

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Sažetak: Procenom hidroloških osobina suše dolazi se do korisnih informacija koje su od značaja prilikom upravljanja vodnim resursima u rečnom basenu. U ovoj studiji su karakteristike suše u basenu Parambikulam-Aliyar u oblasti Tamil Nadu u Indiji, opisane indeksom strujanja (*SDI* - streamflow index) kao indikatorom intenziteta sušnog perioda. Analizirane su pojedinačne promene hodroloških karakteristika, njihova učestanost ponavljanja i mogućnost za predviđanje njihovih budućih vrednosti. Na osnovu dobijenih *SDI* vrednosti, napravljena je klasifikacija intenziteta suše i to kao: umerena, ozbiljna i ekstremna suša. Utvrđeno je da je analizirani basen u oblasti Tamil Nadu bio izložen ozbiljnim sušnim periodima tokom 1970-ih, 1980-ih i 2000-ih naročito u periodu 1972-74, 1982-85, 1987-88 i 2002-04. Hidrološke karakteristike suše su najnepovoljnije u mesecu Januaru i mesecu Junu. Utvrđena je učestanost ponavljanja ozbiljnih sušnih perioda na svakih 80 do 100 godina. Rezultati uve studije se mogu iskoristiti prilikom planiranja mera zaštite od suša u basenu.

Ključne reči: *strujanje, SDI, intenzitet suše, učestanost*

Prijavljen: *Submitted*:	01.07.2014.
Ispravljen: *Revised*:	20.03.2015.
Prihvaćen: *Accepted*:	23.03.2015.

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 85 – 94

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No.1, 2015.
pp: 85 – 94

UDK: 631.358

Originalni naučni rad
Original scientific paper

DEVELOPMENT OF PEDAL OPERATED *SYZYGIUM CUMINI* TREE SHAKER WITH CATCHING UNIT

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***Abstract**:* The objective of this research work was to develop a pedal operated tree shaker for jamun (*Syzygium cumini*) fruit harvesting. The prototype machine was constructed and tested on jamun fruit. The tree shaker was powered by manually foot pedal. The output power of the foot pedal was transmitted through a steel wire rope, where it was converted to a reciprocating motion. The eccentricity of the mechanism was constant to provide stroke lengths of 160 mm. The slider motion was transmitted to the shaker clamp to generate the inertia forces to shaking of the branch. The study included frequency and amplitude to obtain maximum fruit removal percentage, harvesting rate of shaker and physical properties of jamun fruit. Harvesting rate was calculated by weighing both the harvested and unharvested jamun. During the test, the limb of tree was attached to a clamp, which was reciprocated at 160 mm amplitude through steel wire rope (4 mm in diameter) and pedal assembly. The frequency of reciprocation was varied from 40, 50, 60, 70, 80 and 90 cpm respectively. The results were recorded to the maximum fruit removal percentage. Maximum fruit removal percentage was observed to 80-90% by operating the tree shaker at amplitude of 160 mm and a frequency of 90 cpm.

***Key words**: Jamun, mechanical harvesting, shaker, fruit harvester, branch shaker, tree shaker, branch vibrator, fruit catching unit, fruit detaching mechanism, Perishable fruit harvester*

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INTRODUCTION

Jamun *(Syzygium cumini)* fruit is an important member of the family Myrtaceae. It is considered to be indigenous to India and the West Indies, being cultivated in the Philippines, West Indies and Africa. The tree is tall, evergreen and is generally grown as avenue or as wind north to Tamil Nadu in South. It is also found in the lower range of the Himalaya and Kumaon hills in India. The fruits are a good source of iron and are used as an effective medicine against diabetes, heart and liver trouble. There is no improved variety of Jamun for commercial cultivation. However, the most common type grown in north India is known as Ram-jamun. This is large fruited type with oblong deep purple colors (having small seed) which are available in the month of June- July. A Selection known as Narendra Jamun-6 with desirable traits has also been identified at Faizabad [4].

India is the second largest producer of the fruit in the world. World production of Jamun is estimated at 13.5 million tons out of which 15.4 % is contributed by India. India ranks second in production of Jamun in the world. Maharashtra State is the largest Jamun producer followed by Uttar Pradesh, Tamil Nadu, Gujarat, Assam and others. Among the varieties "Konkan bhardoli" is famous. This variety cultivated especially in Konkan region [1]. At present in India two types of Jamun varieties are grown i.e. Ram-Jamun, bearing big sized sweet fruits and Kaatha bearing small sized fruits with acidic pulp.

For most farmers the cost of harvesting operation is probably considered as a major factor in determining whether or not there will be economically successful season. The harvesting of Jamun fruit is predominantly by handpicking for which the grower has to climb up on the tree, which causes of accidents. However, other method that have been employed include; waiting for fruits to drop to the ground and picking them thereafter, and beating of fruits off branches with long poles or stripping fruits together with leaves, followed by winnowing. In many cases, the high cost and short supply of labour may justify the desire for mechanical harvesters by many growers. Mechanical shakers are large scale harvesting equipment with potential applications in wide range of fruits, berries and nuts. In general, harvesting equipment based on principles of a mechanical shaker consist of the shaker, collecting frame (catching units) and conveying devices, usually mounted on a self-propelled carrier, usually a tractor. The basic principle is to accelerate each fruit so that the inertia force developed will be greater than the bonding force between the fruit and the tree.

A major problem associated with mechanical harvesting is fruit damage. With the advent of mechanized harvesting (shakers fruits) significantly reduced the period of harvesting of fruits per tree [7]. In order to reduce fruit damage, the most common approach has been to remove the fruit by shaking the trees and to collect them on a catching surface placed beneath the tree. This method has shown considerable potential for fruits to be processed.

When the vibration of the harvesting fruits beats per minute, affect the entire mass of the clusters, with berries falling on collecting platform and continue to be directed to the underside of the conveyor belt [3].

The fruits are very sensitive and they are subject to rapid deterioration so that must be read carefully and on time. The method and time of harvest has a crucial impact on the fruit quality and hence the possibility of placement. Investments during the raising and maintenance so far are relatively small compared to harvesting costs, so that at hand harvest ranging up to 70% of total costs production [6]. All the operations of hand harvesting ultimately results in loss of considerable human energy, time, money and deterioration of fruits caused by falling on the ground. Due to more drudgery in harvesting of jamun fruits, most of growers have diverted their attention from this fruit crop.

Since the optimal harvesting time depends on the quality of the fruit. Too early harvested fruits with less sugar, more acid, without the aroma, faster shriveling and of inferior quality [2]. It was therefore, necessary to develop harvesting machine with simple design, easy for operation, low cost but with higher working efficiency.

MATERIAL AND METHODS

Experiments were conducted on jamun plantation consisting of eight to ten years old jamun trees at campus of DBSKKV, Dapoli.

Development of an experimental tree shaker

A pedal operated tree shaker was designed and developed for conducting the field experiments on the harvesting of jamun fruit. The shaker consisted of ten main parts, including the foundation frame, middle column, lower arms, upper arm, gear winch, roller assembly, foot pedal, clamping device, fruit catching frame and transportation wheels. The details of component specifications and material were used for the fabrication shown in Tab. 1 and Fig. 1 shows the different components of the shaker.

Table 1. Components, Specifications and Type of Material used for Fabrication

S.N.	Components/ particulars	Specifications	Type of material
1	Foundation frame	1200 mm X 1200 mm and height 1200 mm	Mild steel angles (40 mm X 40 mm X 5mm)
2	Middle column (two pieces)	80 mm X 40 mm X 3 mm and length 3000 mm	Rectangular cross section of mild steel material
3	Lower arms i) right side lower arm ii) left side lower arm	50 mm X 25mm X 3mm and length 3600 mm 50 mm X 25 mm X 3mm and length 4500 mm	Rectangular cross sections of mild steel
4	Upper arm	50 mm X 25 mm X 3mm and length 6000 mm	Rectangular cross sections of mild steel
5	Gear winch	50 mm diameter	Alloy material
6	Roller bearing assembly	50 mm diameter	Cast iron
7	Foot pedal	160 mm X 50 mm and length from centre of the frame 600 mm	M.S plate
8	Clamping device	150 mm X 25 mm,	M.S angles (25 mm X 25 mm X 5mm)
9	Catching frame	1500 mm diameter	Mild steel
10	Transportation of wheel	160 mm diameter	Fibre plastic

Foundation frame

Cross section assembly

Lower arm of lower arms

Gear winch

Roller assembly

Foot pedal

Clamping device

Fruit catching unit

Upper arm with clamp of a developed shaker

Fig.1. Different components of the developed tree shaker for jamun

The square shape foundation of tree shaker was fixed with two rectangular columns vertically at the centre. The vertical columns were supported with four corner supports. The cross shape assembly lower arms were attached to vertical column through pin joint at center point of cross shaped lower arms. Both the outer end of crossed lower arms were attached with wire rope and internally one end was attached to the end point of the upper arm and other internal end of lower arm where attached with rolling assembly which slides on the outer edge of the upper arm. Due to which the height of the upper arm can be increased or decreased by releasing the tension on the lower arm end through steel wire rope. The upper arm was assembled in horizontal direction by fixing one end of lower arm with pin joint and other end were attached with the clamp. As per requirement of height of tree the upper arm can be raised or lowered. The movement of the clamp was fixed by wire rope to clamp and other end was attached to the pedal which was assembled on the foundation frame. At the outer edge of the upper arm pulleys were fixed so as to control the movement of fruit catching unit. A nylon rope whose one end was fixed to fruit catching unit and another end passes over the small pulleys up to the operator hand; which can control the height of fruit catching unit as per requirement. For the operation of the tree shaker two labour required. The assembled view was shown in Fig. 2. and isometric view of the shaker shown in Fig. 3.

Figure 2. Assembled view of developed tree shaker

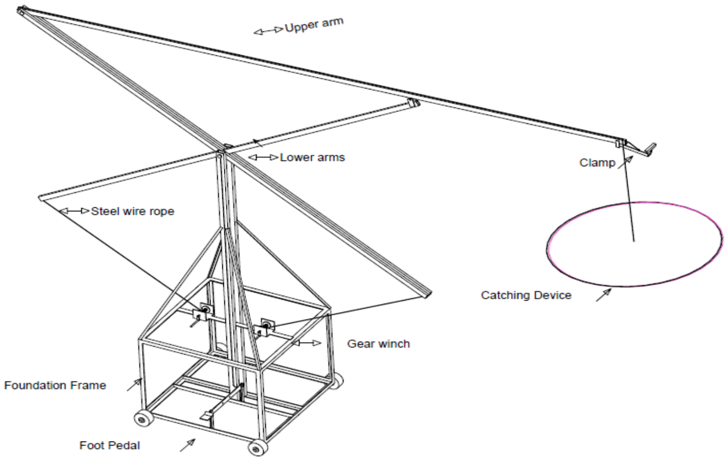

Figure 3. Schematic view of developed pedal operated tree shaker for jamun (Syzygium cumini)

Fruits catching unit

One of the most important disadvantages of mechanical harvesting is fruit damage. In order to resolve this problem, the most common approach has been made to remove the fruit by shaking the trees and collecting them on a catching unit placed beneath the tree.

For this purpose, a circular catching surface as shown in Fig.1, was developed and fabricated. The size of the circular ring was 1500 mm in diameter. The catching surface was made of light weight nylon cloth material from knitted plastic mesh strips and strong yarn. According to the fruit branches the position of catching unit was adjustable through nylon rope. The movement of the wire rope made easier by passing the rope through small pulleys of size 20 mm in diameter were fixed at the top surface of the upper arm.

Determination of the parameter of fruit detachment force/fruit weight

The ratio of fruit detachment force to fruit weight (FDF/W) is used for comparing the suitability of jamun fruit. The fruit detachment force was measured by the help of load cell (0-125 kg) capacity with least count 0.1 kg. The fruit weight was determined with an electronic scale 2.0 kg capacity and 0.01 g divisions.

Determination of branch spring rigidity

In order to observe the sustainability of the branch under the varying shaking frequency it was necessary to find out the spring rigidity index. To determine the branch spring rigidity of jamun trees, a spring dynamometer were used. One end of the dynamometer was attached to the branch of the tree via rope; and other end was held by the hands of the person. The connection point at the branch was chosen to be same as that of the shaker. The branch was pulled horizontally by a person. The maximum displacement of branch was kept up to the detachment of the fruit. The displacement value of branch and dynamometers values were recorded. The spring coefficient was calculated by placing these values in the following equations.

$$C = F/X \qquad (1)$$

Where:

C [$N \cdot mm^{-1}$] - spring rigidity of tree,
F [N] - pulling force,
X [mm] - displacement quantity of branch.

Determination of the effects of shaking frequency on fruit removal percentage

The two most influential parameter on the process of harvesting of berries were the amplitude and frequency of fruit trees [5].

The trees with mature jamun fruits were identified and three to five limbs with appropriate properties and sizes on each tree in different directions were selected for shaking. The remainders of the tree were harvested by workers using traditional harvesting methods. Afterwards, the remaining limbs with fruits were attached to the shaker individually and harvested by applying different frequency combinations. Fruits removed from each limb were collected on the catching surface, filled into polythene bags and then weighed. In the tests, the limbs were shaken at 40, 50, 60, 70, 80 and 90 cpm and 160 mm amplitude. The results of three replicates were analyzed to determine the effects of frequencies and amplitude on the fruit removal percentage.

RESULTS AND DISCUSSION

The results were found on the basis of field performance of a developed tree shaker.

Variation of the fruit detachment force (FDF)/ weight at different maturity times

For the purpose of detachment of fruit from the branch it was necessary to find out the fruit detachment force, the fruit maturity has on important effect on the force required for detachment of fruit. The changes in FDF/W ratio as a function of maturity time were shown in Tab. 2 and Fig. 4; it was observed that the ratio was higher for the unripe fruits and less for the ripe fruits. From graphical representation shows in fig 3.1, it was found that FDF/W ratio for Jamun was decreased from 1.94 to 0.32 N·g^{-1}. within month of days of test.

Table 2. Variation of fruit detachment Force/Weight at different maturity level

Days after fruiting	*FDF (N)*	*Weight of fruit (g)*	*FDF/W*
7	*7.75*	*4*	*1.94*
15	*6.54*	*5*	*1.31*
22	*5.61*	*6*	*0.93*
28	*4.54*	*8*	*0.56*
35	*3.23*	*10*	*0.32*

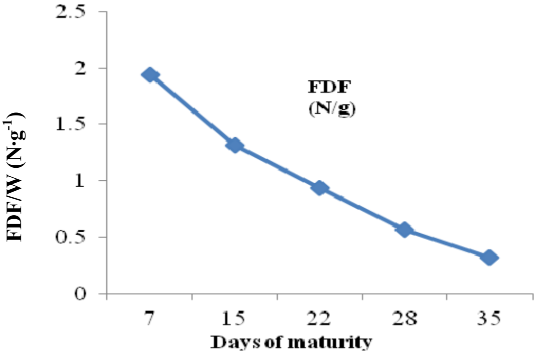

Figure 4. Variation of FDF/W at different maturity level

Branch Spring Rigidity of Jamun

Branch spring rigidity increases with branch diameter. In order to displace the branch up to 150 mm distance minimum force was recorded as 7 kg (68.67 N) and coefficient of spring rigidity was found to be 0.457 N·mm^{-1} for 26 mm branch diameter and maximum force recorded as 38 kg (372.78 N) with coefficient of rigidity as 2.071 N·mm^{-1} for 42 mm branch diameter. It was observed that for the average diameter of branch 34 mm average force of 23.24 kg was required to displace 137.2 mm distance. Correspondingly the average coefficient of spring rigidity was found to be 1.719 N·mm^{-1}. This result was supported for different fruit branches by [6] and [3].

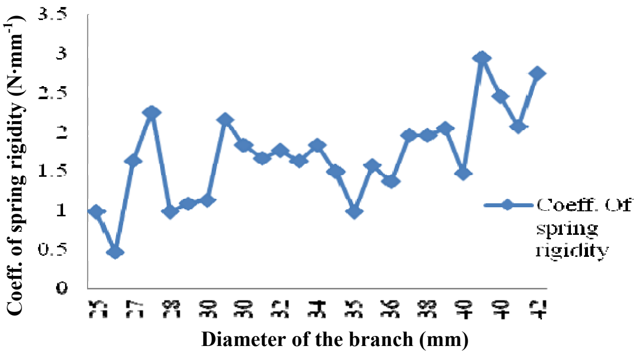

Figure 5. Effect of diameter of the branch on coefficient of spring rigidity

The Effect of Shaking Frequency on Fruit Harvesting

The effects of different frequencies were measured for fruit harvesting and respective observations were placed in Table 3 for different indigenous varieties. From observations it was seen that at 40, 50, 60, 80, and 90 cpm, the average fruit removal percentage of Jamun varieties were 18.17, 50.04, 61.04, 73.29 and 87.08 % respectively. The higher average fruit removed percentage 87.08 % was found at 90 cpm. It might be due to the inertia force develops at this frequency level much greater than the bonding force required detaching the matured fruits. In this process only frequency was varied and amplitude (160 mm) was kept constant.

Table 3. The effects of different shaking frequencies on fruit harvesting

Branch	*Weight of fruits remove (g)*	*Weight of Fruits un remove (g)*	*Total weight (g)*	*Fruit removal (%)*	*Frequency (cpm)*
1	160	440	600	26.67	40
2	120	606	726	16.53	40
3	220	526	746	29.49	40
			Average	24.23	40
1	390	440	830	46.99	50
2	450	660	1110	40.54	50
3	580	220	800	72.50	50
			Average	53.34	50
1	337	530	867	38.87	60
2	468	320	788	59.39	60
3	890	380	1270	70.08	60
			Average	56.11	60
1	378	564	942	40.13	70
3	752	240	992	75.81	70
3	960	260	1220	78.69	70
			Average	64.65	70
1	780	510	1290	60.47	80
2	1030	360	1390	74.10	80
3	820	206	1026	79.92	80
			Average	71.49	80
1	1386	270	1656	83.70	90
2	1138	130	1368	83.19	90
3	1560	130	1690	92.31	90
			Average	86.40	90

Effect of vertical distance of catching unit from limb on fruit damage

Jamun fruits normally fall on the ground when they become mature. The fruits were very delicate, after falling on the ground they become destroyed and deterioration takes place. In this case fruits were catch at certain required distance from branch by using catching unit to reduce the damage percentage of the fruits. The study was conducted to find out the exact vertical distance of the catching unit from the branch, so as to get minimum fruit damage. The table 5.8 shows the fruit damage percentage and catching efficiency at various distances from fruit limb. It was observed that the highest fruit damage percentage and catching efficiency i.e. 20% and 60.1% were occurred at 4m were as at 1m distance of fruit catching unit the damage percentage was nil and catching efficiency was 89.74%.

Table 4. Fruit damage percentage

Catching unit from fruit limb (m)	*Fruit damage percentage (%)*	*Total fruits collected in catching unit (kg)*	*Total fruits dropped on the ground (kg)*	*Catching efficiency (%)*
1.0	*0*	*22.76*	*2.6*	*89.74*
1.5	*2*	*18.22*	*2.9*	*86.26*
2.0	*6*	*15.65*	*3.5*	*81.26*
2.5	*10*	*11.70*	*3.8*	*75.48*
3.0	*15*	*8.20*	*4.0*	*67.21*
3.5	*18*	*7.60*	*4.0*	*65.51*
4.0	*20*	*6.18*	*4.1*	*60.10*

CONCLUSIONS

1. The performance of fruit harvester was found to be satisfactory.
2. The Fruit detachment force/weight ratio of Jamun fruit decreased with increasing maturity time. Consequently, the most appropriate time for harvesting of Jamun was found in the month of May, June and July.
3. To obtain maximum fruit removal with minimum vibration and reactive force, the limb shaker should be operated in the range of 160 mm amplitude and 90cpm frequency. The maximum fruit removal percentage 86.4% was obtained at 90cpm frequency and the harvesting capacity was observed to be 0.06 ha/day.
4. The efficiency of the catching unit was obtained to be 89.74 % at 1 m height from the fruit limb towards the ground.
5. The catching unit of nylon cloth material surfaces which are at 1 m height from the fruit limb towards the ground reduced or no fruit damage percentage by compared to that caused by impact with the ground.
6. Fruit removal percentage increased with an increased in shaking Frequency.
7. Limb position, limb length and size of the tree affected the fruit removal percentage.
8. The maneuverability of the shaker was satisfactory but sometimes the operator had some trouble in swinging the shaker through the tree canopy to attach on to the limbs and in positioning the shaker when operating on sloping terrain.

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RAZVOJ TRESAČA SA HVATAČEM ZA STABLA *SYZYGIUM CUMINI* NA NOŽNI POGON

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Sažetak: Cilj ovog istraživanja bio je da razvije tresač sa pogonom od pedala za berbu jamuna (*Syzygium cumini*). Prototip mašine je konstruisan i testiran na voću jamun. Tresač ima pogon od nožnih pedala. Izlazni pogon sa pedala je prenet čeličnim užetom i pretvoren u oscilatorno kretanje. Ekscentrični mehanizam je konstantno proizvodio oscilacije sa hodom od 160 mm. Kretanje klizača je preneto na hvatač tresača da generiše inercijalne sile za trešenje grane. Studija je uključila frekvenciju i amplitudu za postizanje maksimalnog procenta skidanja voća, norme ubiranja tresača i fizičkih svojstava voća. Norma ubiranja je izračunata merenjem ubranih i neubranih plodova. Tokom testiranja, grana drveta je stezana hvatačem koji je oscilovao sa amplitudom od 160 mm preko čeličnog užeta (prečnika 4 mm) i sklopa pedala. Frekvencija oscilovanja je iznosila 40, 50, 60, 70, 80 i 90 min^{-1}, redom. Rezultati su praćeni pri maksimalnom procentu skidanja plodova. Maksimalni zabeleženi procenat skidanja iznosio je 80-90% pri radu tresača sa amplitudom od 160 mm i frekvencijom od 90 min^{-1}.

Ključne reči: *jamun, mehanička berba, tresač, berač voća, tresač grana, tresač stable, vibrator grana, uređaj za hvatanje voća, mehanizam za odvajanje voća, berač za kvarljivo voće*

Prijavljen: *Submitted*:	17.08.2014.
Ispravljen: *Revised*:	16.02.2015.
Prihvaćen: *Accepted*:	04.03.2015.

Univerzitet u Beogradu
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Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 1, 2015.
Strane: 95 – 102

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No.1, 2015.
pp: 95 – 102

UDK: 635.63: 631.5

Originalni naučni rad
Original scientific paper

ENERGY EFFICIENCY ASSESSMENT OF MICRO IRRIGATION

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Abstract: In India, variation in crop yield is occurs due to wide variation in energy inputs, agro-climatic conditions, and different resources used. Keeping this in view, a study has been carried out to find the energy efficiency of micro irrigation. The field experiment was carried out with drip method of irrigation (*DMI*) and conventional method of irrigation (*CMI*) at 100 per cent *ET* at two locations in Jalgaon district of Maharashtra during 2009-'10. The irrigation water requirement of the banana crop was noticed minimum in *DMI* compared to *CMI* treatment indicating 35.14 and 29.24 per cent water saving and 38.96 and 33.41 per cent electricity saving in experimental and farmer's fields, respectively. Early flowering and harvesting was noticed with reduction in growth period in *DMI* against *CMI*. The banana yields in *DMI* were (72.6 and 67.4 $t \cdot ha^{-1}$) higher against *CMI* (59.1 and 52.5 $t \cdot ha^{-1}$) under experimental and farmer's fields, respectively. In *DMI* about 32.70 and 29.99 per cent input energy savings and 19.73 and 14.09 per cent increase in output energy were noticed against *CMI*. Also, the higher energy efficiency of 13.5 and 12 was noticed in *DMI* as compared to *CMI* (7.6 and 7.4). In both the fields, 17.01 and 20.36 per cent higher BC ratios were recorded in *DMI* (2.27 and 2.01) over *CMI* (1.94 and 1.67).

The present study reveals that drip irrigation has a definite role in minimizing the energy use in terms of water and electricity as well as reducing the impacts of climate change in Indian agriculture.

Key words: *banana (Musa sp.), drip irrigation, energy consumption, efficiency and CO_2 emission*

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We are thankful for Jain Irrigation Systems Ltd. Jalgaon, Maharshtra for providing all the facilities and motivating us during this project.

INTRODUCTION

Global warming is the most dreaded problem of the new millennium. Greenhouse gases (*GHG*s) mainly contribute for the cause of global warming. There are various sources of *GHG*s emission among that power generation based on fossil fuel is the major source. The electricity requirement for pumping of water and its inefficient utilization are also a cause of concern. Conventional irrigation methods are employed for more than 80 per cent of the world's irrigated lands yet their field level application efficiency is only 40-50 per cent [8]. In contrast, drip irrigation has field level application efficiencies of 70-90 per cent as surface runoff and deep percolation losses are minimized [10].

All agricultural operations require energy inputs in various forms (human labor, animal power, fertilizer, fuels and electricity) and in varying magnitudes with variation as per different agro-climatic zones and even farmers to farmers. The largest need of energy services is for pumping of irrigation water. Various research studies showed that water saving, electricity saving, irrigation efficiencies and yield of crops using drip irrigation are substantially higher than crops irrigated by the flood method of irrigation ([2] [11]).

In India 52 per cent of its total power comes from coal from which agriculture consumes 28.5 per cent of total electricity [4]. The power generation in India has increased from 1400 Mw in 1947 to 2.00 Lakhs Mw at the end of 2010-11, which is comprised of power from hydroelectric, thermal, wind and nuclear power stations. The power availability for production agriculture in India is 1.5 $kW \cdot ha^{-1}$ and lies higher its requirement in Punjab which is about 3.5 $kW \cdot ha^{-1}$ [7]. According to BERI [12], India is among the 10 fastest growing economies in the world and fossil fuel share is expected to rise to 74 per cent of total energy used by 2010, with corresponding increase in CO_2 emissions to 1,646 Mt. The use of fossil fuels increases the *GHG*s emission. Thus, energy efficiency in agriculture would have huge impact on overall scenario.

Considering all the above aspects, a pilot study was undertaken to study their impacts on banana (*Musa sp.*) crop, as this is one of the major consumer of water and energy. Banana is a globally important fruit crop produced in tropical and subtropical regions of developing countries with 97.5 M t of production. India is the world's largest producer of banana, accounting for about 27 per cent to the global output. Taking this fact into consideration, the present research work was undertaken in order to generate the scientific information regarding the same aspect and standardize the energy savings for banana crop due to use of drip irrigation compared to conventional irrigation.

MATERIAL AND METHODS

Study area

A study was conducted at two different locations in Jalgaon district of Maharashtra ($21^0$01' N, $75^0$34' E and 209 m) during May 2009 to May 2010. One at the Research and Development Farm of the Jain Irrigation Systems Ltd., and another set up in farmer's field. In both the fields, soils are well drained and slightly alkaline with good water holding capacity. Banana crop (*Musa sp.*) cv. Grand Naine (tissue cultured) was selected with 1.82 x 1.82 m planting distance. Two treatments, drip method of irrigation (*DMI*) and conventional method of irrigation (*CMI*) were divided in to 10 equal parts (replication) by maintaining the same plant population and irrigation was applied by considering 100 per cent evapotranspiration (*ET*). The statistical analysis of the treatments was done for all the parameters recorded during the study by the technique of Analysis of Variance (ANOVA).

Water requirements

The peak water requirement for the banana crop was calculated from the following equation.

$$PWR = \frac{A \times B \times C}{E} \tag{1}$$

Where:

PWR [$mm \cdot d^{-1}$] - peak water requirement,
A [$mm \cdot d^{-1}$] - evapotranspiration rate (pan co-efficient x evaporation),
B [-] - crop factor,
C [-] - canopy factor,
E [-] - efficiency of irrigation system.

The daily evaporation data was obtained from Class-A open pan evaporimeter. Then from peak water requirement, the amount of water required per irrigation was calculated as follows.

$$Volume\ of\ water\ required\ (m^3) = \frac{PWR\ (mm \cdot d^{-1}) \times treatment\ area\ (m^2)}{1000} \tag{2}$$

In conventional irrigation treatment, the water requirement was calculated in terms of depth of irrigation using the following equation.

$$D = \frac{(M_{fc} - M_{bi})}{100} \times A_s \times d_s \tag{3}$$

Where:

D [cm] - net amount of water to be applied during irrigation,
M_{fc} [%] - moisture content at field capacity,
M_{bi} [%] - moisture content before irrigation,
A_s [$g \cdot cc^{-1}$] - bulk density of soil,
d_s [cm] - effective root zone depth.

From the net amount of water, the quantity of water required for irrigation (m^3) was measured by multiplying the net depth of irrigation (m) with the treatment area (m^2). Then, calculated amount of water applied to fields by deducting the effective rainfall at every alternate day in *DMI* treatment and as per field moisture status in *CMI* treatment.

Observations recorded

The observations such as daily evaporation (mm), water consumption (kL), number of pumping hours per irrigation (h), electricity consumption (kWh), number of labours required for different farm operations, growth parameters, growth stages and yield parameters were recorded during the study.

Energy evaluation

The energy consumption in the farm operations was determined by calculating the total energy input which included animate labors, water for irrigation, electricity for pumping, fertilizers and micronutrients for crop improvement. Also, the output got from crop yield and biomass of plant was considered as the output energy.

Biomass is considered as strategic potential, not only because it is a renewable source of energy and it is widespread, but also because its application can provide a sufficient amount of energy to reduce emissions of CO_2 and other greenhouse gases, resulting in a minimum negative impact on environment [3]. Energy from inputs and outputs was calculated by converting their physical units into respective energy units by using appropriate energy equivalents [9], were used during the study. The energy figures used in the study were expressed in mega joule (MJ) and giga joule (GJ) units (Tab. 1).

Table 1. Energy equivalents for different energy input and output sources

Particulars	*Input/ Output units*	*Energy equivalents (MJ)*	*Particulars*	*Input/ Output Units*	*Energy equivalents (MJ)*
Human labor			*Fertilizers*		
Man	*Man-hour*	*1.96*	*Nitrogen, N*		*60.6*
Woman	*Woman-hour*	*1.57*	*Phosphorous, P_2O_5*		*11.1*
Animals			*Potassium, K_2O*	*kg*	*6.7*
Bullocks (Wt. above 450 kg)	*Pair-hour*	*14.05*	*Farmyard manure FYM*		*6.7*
Fuel			*Chemicals*		
Diesel	*litre*	*56.31*	*Superior*		*120*
Irrigation water	*kilolitre*	*1.02*	*Zinc sulphate*	*kg*	*209*
Power			*Inferior*		*10*
Electricity	*kWh*	*11.93*	*Fruit*		
Machinery			*High value (Banana)*	*kg*	*11.8*
Electric motor	*kg*	*64.8*	*By Products*		
Tractor	*Tractor-hour*	*331.59*	*Stalk*	*kg (Dry mass)*	*18*
Tractor trailer	*Per tone per km*	*4.86*	*Leaves*		*10*

Source: [5] [6] [9]

RESULTS AND DISCUSSION

Water and electricity consumption

The minimum water was required in *DMI* (1455.6 and 1669.7 $mm \cdot ha^{-1}$) when compared to its counterpart *CMI* treatment (2244.2 and 2359.8 $mm \cdot ha^{-1}$) in both the fields (Tab. 2). Also, 35.14 and 29.24 per cent water saving was noticed in *DMI* treatment in both the fields. The number of irrigations applied during the crop period was observed higher in *DMI* treatment (151 and 126) but the amount applied in each irrigation was very less than its counterpart. It was to maintain the moisture level at the root zone of plant, water was applied drop by drop in *DMI* as compared with *CMI* treatment. In addition, the number of pumping hours required for irrigating hectare area was minimum in *DMI* treatment (397.7 and 456.2 h·ha^{-1}). Due to less water consumption and less number of pumping hours the electricity consumption for pumping of irrigation water was also found to be minimum in *DMI* treatment in both the fields. Also, 38.96 and 33.41 per cent saving of electricity used for pumping in *DMI* treatment was observed in the experimental and farmer's fields, respectively.

Table 2. Irrigation water and electricity consumption in irrigation methods

Particulars	*Experimental field*		*Farmer's field*	
	DMI	*CMI*	*DMI*	*CMI*
Depth of irrigation applied (mm·ha^{-1})	*1455.6*	*2244.2*	*1669.7*	*2359.8*
Total water consumption (kL·ha^{-1} or m^3·ha^{-1})	*14.556*	*22,442*	*16.697*	*23.598*
Total electricity consumption (kWh·ha^{-1})	*4657.8*	*7630.3*	*5343*	*8023.5*
Total number of irrigations applied	*151*	*40*	*126*	*42.1*
Total pumping hours used for irrigation application (h·ha^{-1})	*397.7*	*1726.3*	*456.2*	*1815.3*
Hours used per irrigation	*2.6*	*43.2*	*3.6*	*43.1*

Growth and yield parameters

The *DMI* treatment had better and early growth as indicated by higher pseudo stem height, pseudo stem girth and number of functional leaves as compared to *CMI* treatment (Tab. 3). Drip irrigation treatment resulted in early flowering and harvesting and thus reduction in crop period by 22.1 and 24.2 days as compared with its counterpart. The banana crop performed well in terms of yield and yield contributing parameters under *DMI* treatment. Higher bunch weights of 24 and 22.3 kg were noticed in *DMI* compared to 19.6 and 17.4 kg in *CMI* under different fields. The banana yields in *DMI* were 72.6 and 67.4 t·ha^{-1} against 59.1 and 52.5 t·ha^{-1} in *CMI* resulting in 22.84 and 28.38 per cent yield increase under experimental and farmer's fields, respectively.

Table 3. Effect of irrigation methods on growth and yield parameters of banana crop

Parameters	*Experimental field*		*Farmer's field*	
	DMI	*CMI*	*DMI*	*CMI*
Pseudo stem height at flowering stage (cm)	*192.6*	*189.2*	*193.1*	*183.3*
Pseudo stem girth at flowering stage (cm)	*71.7*	*69.5*	*72.5*	*70.9*
Number of functional leaves at flowering	*16.6*	*16.1*	*16.4*	*16.3*
Days required to flowering stage	*232.9*	*253*	*230.6*	*251.6*
Days required to harvesting stage	*321.5*	*343.6*	*312.8*	*337.0*
Bunch weight (kg)	*24*	*19.6*	*22.3*	*17.4*
Yield (t·ha^{-1})	*72.6*	*59.1*	*67.4*	*52.5*
Biomass from stem and fallen leaves (kg)	*9.0*	*8.1*	*8.9*	*8.5*

Different efficiencies

Tab. 4 shows there was a remarkable increase in water, fertiliser, electricity use and pumping efficiency in *DMI* treatment as compared to *CMI* treatment. This might be attributed to the efficient use of water and fertilisers, reduced electricity for pumping and pumping hours in *DMI* treatment. Due to efficient application and use of inputs, the yield also increased, which was reflected in the increase in input efficiency.

Table 4. Effect of irrigation methods on different efficiencies

Efficiency	*Experimental field*		*Farmer's field*	
	DMI	*CMI*	*DMI*	*CMI*
Water use efficiency (kg·m^{-3})	*5.0*	*2.6*	*4.0*	*2.2*
Fertilizer use efficiency	*0.25*	*0.08*	*0.24*	*0.07*
Electricity use efficiency (kg·kWh^{-1})	*15.6*	*7.8*	*12.6*	*6.5*
Pumping efficiency (kg·hph^{-1})	*36.5*	*6.9*	*29.6*	*5.8*

Energy analysis

The input energy usage was very high in case of *CMI* treatment (121.68 and 124.53 GJ·ha^{-1}) against *DMI* treatment (81.89 and 87.18 GJ·ha^{-1}). The energy savings of 32.70 and 29.99 per cent was found in *DMI* treatment as compared to *CMI* treatment in experimental and farmer's fields (Tab. 5). This might be due to less consumption of inputs and efficient use of energy sources i.e. water, fertilizers, electricity, pumping hours and human labor in *DMI* treatment. For irrigation and fertigation operation the electricity energy, water energy and human energy were used maximum in case of *CMI* treatment. The yield and biomass gain from the banana crop production was converted into output energy by multiplying with appropriate energy equivalents. In both the fields, 19.73 and 14.09 per cent increase in output energy were noticed in *DMI* against *CMI* treatment. With regard to energy efficiency in the production of banana crop, *DMI* treatment was found excellent in both the fields. The present results on net energy, specific energy and energy productivity gain in banana crop production were also found maximum in *DMI* treatment as compared with *CMI* treatment. This might be attributed to the maximum gain on output energy with minimum consumption of input energy.

Table 5. Energy analysis in banana crop production

Source	*Experimental field*		*Farmer's field*	
	DMI	*CMI*	*DMI*	*CMI*
Input energy (GJ·ha^{-1})	*81.89*	*121.68*	*87.18*	*124.53*
Output energy (GJ·ha^{-1})	*1107.88*	*925.30*	*1045.92*	*916.78*
Energy ratio / Energy efficiency	*13.5*	*7.6*	*12*	*7.4*
Net energy gain (GJ·ha^{-1})	*1025.99*	*803.62*	*958.73*	*792.25*
Specific energy (MJ·kg^{-1})	*1.1*	*2.1*	*1.3*	*2.4*
Energy productivity (kg·MJ^{-1})	*0.9*	*0.5*	*0.8*	*0.4*

Economics

The acceptance of new technology by the farming community depends on the economic indicators in the crop production. In the present study, *DMI* treatment recorded higher gross returns (3,91,932 and 3,63,960 Rs·ha^{-1}) and net returns (2,19,540 and 1,82,594 Rs·ha^{-1}) in both the experimental and farmer's fields. However, the cost of cultivation of banana under investigation in *DMI* treatment (1,72,392 and 1,81,366 Rs·ha^{-1}) was 4.99 and

7.10 per cent higher than the *CMI* treatment (1,64,206 and 1,69,346 Rs·ha^{-1}); it might be due to higher investment in drip accessories. Even though, *DMI* treatment recorded 17.01 and 20.36 per cent higher BC ratios (2.27 and 2.01) in both the fields, it was mainly due to higher yield and gross returns as compared with its counterpart.

CONCLUSIONS

The present study clearly indicates that the drip irrigation technology was very beneficial for banana crop not only in terms of water saving and fertilizer saving but also it saved considerably the electricity required for pumping of water required for irrigation. The present study was attempted to minimize the carbon dioxide emissions that mainly leads to the global warming, by adopting the sustainable drip irrigation technology in banana crop.

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ENERGETSKA EFIKASNOST SISTEMA MIKRO-NAVODNJAVANJA

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Sažetak: U Indiji, na prinos ratarskih kultura utiču agro-klimatski uslovi regiona, tehnologija gajenja i utrošena energija putem repromaterijala, navodnjavanja, tehničkih sistema i ljudskog rada. Imajući sve ovo u vidu, sprovedeno je istraživanje na polju potrošnje energije putem mikrosistema za navodnjavanje. Poljsko ispitivanje je podrazumevalo dva tipa sistema i to sistem mikrokapanja (*DMI*) i konvencionalni sistem navodnjavanja (*CMI*) sa 100% ET na dve lokacije u Jalgaon-u u okrugu Maharashtra tokom 2009 i 2010. Kod useva banane je, u sistemu *DMI* bila minimalna potrošnja vode u poređenju sa *CMI* sistemom, sa 35.14 i 29.24 % uštedom vode i 38.96 i 33.41% uštedom električne energije, na eksperimentalnom polju i kod farmera redom. U *DMI* sistemu je registrovano ranije cvetanje i ubiranje kao i skraćenje perioda do ubiranja, u poređenju sa *CMI* sistemom. Prinos banana u *DMI* sistemu je, takođe, bio viši u poređenju sa *CMI* sistemu. Ostvareni prinosi su bili 72.6 i 67.4 $t \cdot ha^{-1}$ i u *CMI* sistemu 59.1 i 52.5 $t \cdot ha^{-1}$, na eksperimentalnom polju i kod farmera, redom. U *DMI* sistemu je ostvareno 32.70 i 29.99% uštede u energiji sa istovremenim porastom energetskog output-a za 19.73 i 14.09% u poređenju sa *CMI*. Energetska efikasnost u *DMI* sistemu je takođe bila viša u poređenju sa *CMI* sistemom. U *DMI* sistemu ostvaren je porast energetske efikasnosti za 13.5. i 12% dok su u *CMI* sistemu te vrednosti iznosile 7.6 i 7.4. Na oba polja je registrovan viši *BC* u slučaju *DMI* sistema.

Prikazana studija ukazuje da se primenom drip irigacije mogu ostvariti zanačajne uštede u energiji u smislu smanjenja potrošnje vode i niže potrošnje električne energije. Ovim sistemom navodnjavanja se može umanjiti uticaj klimatskih promena u Indijskoj poljoprivredi.

Ključne reči*: banana (Musa, sp), mirko-navodnjavanje kapanjem, potrošnja energije, efikasnost i CO_2 emisija*

Prijavljen: *Submitted*:	17.07.2014
Ispravljen: *Revised*:	15.03.2015
Prihvaćen: *Accepted*:	18.03.2015.

CIP – Каталогизација у публикацији
Народна библиотека Србије, Београд

631(059)

ПОЉОПРИВРЕДНА техника : научни часопис = Agricultural engineering : scientific journal / главни и одговорни уредник Горан Тописировић. – Год. 1, бр. 1 (1963)- . - Београд; Земун : Институт за пољопривредну технику, 1963- (Београд : Штампарија ”Академска издања”) . – 25 cm

Тромесечно. – Прекид у излажењу од 1987-1997. године
ISSN 0554-5587 = Пољопривредна техника
COBISS.SR-ID 16398594