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EDITORIAL

Recently I had a chance to participate in some international meetings abroad. They were the CIGR Congress in Quebec, Canada, the ASABE International Annual Meeting in Pittsburgh, Pennsylvania, and the 50th anniversary Symposium of Mongolian Agricultural University in Mongolia. After visiting these meetings, I felt strongly that we could not solve the problem of imbalance between human and biological environment without the cooperation of people all over the world. The river flowing in Ulan Bator was very beautiful and there were people bathing, but the water was not suitable for drinking like it was in the past times. Also, the quantity of water was about one third of what it had been in the past. This seemed to be because of the forest destruction in the upstream mountains. After setting one foot out of Ulan Bator, there was a vast green meadow in front of me. There were caravans and many cattle breeders, just like the good old days. The sky was blue, the clouds were white, and the natural landscape was absolutely beautiful. However, people say that we cannot ignore the threat of creeping environmental pollution, even in Mongolia.

Relating to the environmental problem in Japan, I grew up in a streamside town. I used to drink the water in the river, but now, it cannot be drunk like the days of my childhood. Japan cannot get back the clean water just by undertaking domestic effort because of the problem of the west wind carrying many polluted materials from newly industrializing countries such as China. That is, if you want to drink good water in Japan, the worldwide environmental problem must be solved. We can say the same thing with the food problem. There is always much food left in some countries, while there is always hunger in other countries, regardless of the expanding disparity in wealth. I have not seen this structure collapsing since I started writing for AMA and I can hardly imagine it changing anytime soon.

However, from having seen many research results, I feel that there are revolutionary changes being made in agricultural mechanization these days. One of the changes is the expanding of advanced technologies such as the computer and the internet. Also, the movement to develop agricultural robots is active. This September, an international collaboration meeting between the Chinese Academy of Agricultural Mechanization Sciences and the Asian Association for Agricultural Engineering will be held in Shanghai, China. The problems in Asia are as important as the problems of the world. To solve the energy problems regarding the Asian agricultural environment, close-knit cooperation between Asian countries is strongly needed. It is no exaggeration to say that there are very few problems left that can be solved without global cooperation. Various technical research is done in many areas, and the internet allows us to link to those research results instantly. The intellectual power of the human is making a significant advance. We, the AMA, would like to continuously bring people together to solve agricultural and environmental problems.

Yoshisuke Kishida
Chief Editor

July, 2010

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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Ergonomic Intervention in Sugarcane Detrashing

by

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Abstract

Sugarcane detrashing is a highly labour intensive operation. Conventional detrashing by hand leads to serious health hazards for the workers. In view of the importance of the detrashing operation, mechanical detrashers have been introduced. The available mechanical detrashers viz., IISR sugarcane detrasher, OUAT sugarcane detrasher and TNAU sugarcane detrasher with selected male and female subjects were ergonomically evaluated to assess their suitability for men and women farm workers for reduced drudgery and adequate comfort. The detrashing was performed between 150 to 210 days after planting. The TNAU sugarcane detrasher (SCD_3), which registered the lowest value of ergonomic evaluational parameters and highest stripping capacity with minimum damage to sugarcane stalks was identified. Necessary ergonomic refinements (viz., reduction of length of knife supporting stem, sliding supporting stem and knife base, wooden handle for firm grip and reduction of weight) were made for enhanced comfort of the operator without jeopardizing the efficiency of the detrasher. The mean value of heart rate, energy cost, and oxygen consumption rate in terms of percent VO_2 maximum and work pulse of male subjects with the refined TNAU sugarcane detrasher (ESCD) was 101.12 beats min^{-1}, 14.74 kJ min^{-1}, 34.88 percent of VO_2 maximum and 30.55 beats min^{-1}, respectively. The corresponding values for female subjects were 112.76 beats min^{-1}, 16.52 kJ min^{-1}, 47.91 percent of VO_2 maximum and 44.35 beats min^{-1}, respectively. The effectiveness of ergonomic refinements made with the sugarcane detrasher was reflected in terms of significant reduction in physiological stress and 4.9 percent increase in stripping capacity. The ergonomic refined TNAU sugarcane detrasher resulted in 5.5-6.6 percent savings in cost and 5.6-5.8 percent savings in time of detrashing when compared to the existing model of the TNAU detrasher. Use of the ergonomic refined TNAU detrasher resulted in 13.0 percent and 14.5 percent saving in cost and time, respectively, when compared to conventional hand detrashing.

Introduction

Detrashing in the sugarcane crop is an important agricultural operation, affecting crop yield. However, it is a labour intensive operation that accounts for about 10 percent of the total labour requirement during a cultivating season. Sugarcane detrashing is divided into three phases viz., touching and compressing, bending and deforming and sliding and detrashing the leaf sheath. The arduous operation of detrashing sugarcane is usually performed manually with both hands. The workers wear a full sleeve shirt and cover the head and face with cloth for preventing from injury. Even though they wear full sleeve shirts, spines (thorny hair like structures found on leaf sheaths) cause pricking of the hands causing "Irritant Contact Dermatitis (ICD)", "Allergic dermatitis (AD)" and "Keratinization" (The deposition of keratin in cells occurring in the epidermis of the skin and structures in nails and hair. The cells become flattened and lose their nuclei). Contact dermatitis results in large burning and itchy rashes, and these can take anywhere from several days to weeks to heal. The symptoms of both include red rash, blister or welts and itchy and burning skin. The leaf blades present in the cane irritate and scratch the hands forming "abrasion and fissures". Recently, some improved hand tools have been introduced. In view of the importance of the detrashing operation, it is desirable to ergonomically evaluate the available mechanical detrashers to assess their suitability for men and women farm workers for reduced drudgery and adequate comfort.

Review of Literature

Srivastava *et al.* (1982) developed a simple manual detrasher cum collector. It increased the efficiency of the labour by 5-7 times. The process of detrashing with the help of this equipment is not strenuous. The exertion is not localized.

Materials and Methods

Sugarcane stalk has a large number of leaves (30-35) equal to the number of internodes under good management systems. However, all these leaves are not productive. Only the top eight to ten leaves are required for optimum photosynthesis. In fact, the bottom green leaves are parasitic on the upper productive leaves and drain out the food reserves (photosynthesis), which other wise could be used for stalk growth. Therefore, in sugarcane it is important to remove the lower dry and green leaves. Detrashing should be taken up after the cane formation around 150 days after planting. Thereafter, it could be done at bimonthly intervals depending upon the labour availability. Critical periods for detrashing of cane are between 150-210 days after planting. This ensures higher cane yield.

Few models of detrashers have been developed for detrashing of sugarcane. A detrasher is a small hand tool for stripping green and dry leaves and detopping of cane after harvest. Detrashers are mainly used in standing sugarcane crops. The buds in the internodes are damaged while detrashing the leaves from the sugarcane. Bud damage is claimed as beneficial when the sugarcane is cut for sugar factories because removal of buds prevent sugarcane from sprouting at the rainy season, sugar inversion and lodging. The detrasher strips, separates and pushes the leaf sheath away from stalk. Detrashers used in different regions of Tamil Nadu and India were procured and selected for the ergonomical evaluation. Three types of sugarcane detrasher used were:

i. IISR sugarcane detrasher (SCD_1)
ii. OUAT sugarcane detrasher (SCD_2)
iii. TNAU sugarcane detrasher (SCD_3)

Iisr Lucknow Sugarcane Detrasher (Scd_1)

For detrashing and detopping, IISR has developed a hand tool which does the job of stripping of dry leaves and cutting the green top satisfactorily. It consists of a pair tongs, the jaws of which close to form a square and extend beyond the square to form a "V" in front. One of the two limbs is bent down and provided with a wooden handle (**Fig. 1**). A light tension spring holds the jaws closed. A knife is welded on the stem of the detrasher for detopping the cane after harvest. The cane is gripped between the jaws of the tool and drawn downward in one or two sweeps. The stripper removes the dry/green leaves by separating them and pushing them away from cane stalk. The green top is then cut with a knife provided for this purpose on the stem of the stripper. This type of sugarcane detrasher is used in the Northern region of India.

Ouat Sugarcane Detrasher (Scd_2)

The sugarcane detrasher developed at OUAT Bhubaneswar has similar configurations to that of the

Fig. 1 IISR Cane detrasher

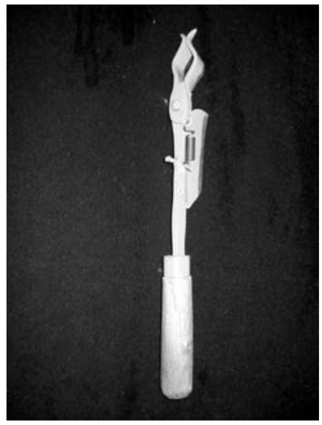
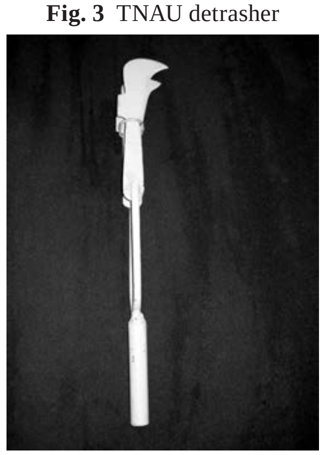


Fig. 2 OUAT cane detrasher

Fig. 3 TNAU detrasher



IISR model (**Fig. 2**). The knife is absent in this model. The sugarcane stem is held between the two jaws and the detrasher is forced vertically for detrashing the dry leaves from the sugarcane.

Tnau Sugarcane Detrasher (Scd_3)

This is the tool for detrashing the green/dry leaves from the standing crop of the sugarcane. It consists of two curved knives welded to two ends of the U shaped stem. The stem is attached to a hollow metal pipe **(Fig. 3**). An adjustable oval shaped loop is provided to increase or decrease the gap between two knives depending on the diameter of sugarcane stalk. The knives are inserted between the internodes at the top and pulled vertically down for removing the dry and unwanted leaves.

Twelve male and female subjects were selected for the investigation based on the age and fitness. They were screened for normal health through medical examinations. The IISR sugarcane detrasher (SCD_1), OUAT sugarcane detrasher (SCD_2) and TNAU sugarcane detrasher (SCD_3), with selected male and female subjects, were ergonomically evaluated. The detrashing in sugarcane with different detrashers was performed between 150 to 210 days after planting. All twelve male and female subjects were calibrated in the laboratory condition by indirect assessment of oxygen uptake. Oxygen consumption was measured by using the computerized ambulatory metabolic measurement system (Metamax-II) while running on the computerized treadmill (Viasys LE 200CE model). The corresponding heart rate was recorded using Polar Vantage NV computerized heart rate monitor (S 810i) at sub maximal loads. The maximum heart rate of all the selected male and female subjects was computed using the equation proposed by Astrand (1960) and the arrived values of maximum aerobic capacity (VO_2 maximum) for all the subjects. The maximum aerobic capacity of the selected twelve male subjects varied from 1.84 to 2.19 l min^{-1} and, for female subjects, from 1.513 to 1.736 l min^{-1}. All the twelve male and female subjects were calibrated in the laboratory by indirect assessment of oxygen uptake. The values of heart rate at resting level and 6^{th} to 15^{th} minute of operation were taken for calculating the physiological responses of the subjects (Tiwari and Gite, 1998). The stabilized values of heart rate for each subject from 6^{th} to 15^{th} minute of operation were used to calculate the mean value for cono weeders. To ascertain whether the operation of all the selected weeders were within the acceptable workload (AWL), the VO_2 maximum for each treatment was computed and recorded. The acceptable workload (AWL) for Indian workers was the work consuming 35 percent of VO_2 maximum (Saha *et al.*, 1979). To have a meaningful comparison of physiological response, ΔH values (increase over resting values) for heart rate (work pulse) were calculated (Tiwari and Gite, 1998). The calculated values of work pulse for each operation were compared with the acceptable work pulse values of 40 beats min^{-1} as the limit of continuous performance (Brundke, 1984).

The experiment was conducted in sugarcane fields located at Perambalur and Thallavadi villages of Tamil Nadu. Field experiments were conducted with the IISR sugarcane detrasher (SCD_1), OUAT sugarcane detrasher (SCD_2) and TNAU sugarcane detrasher (SCD_3) during the month of June and July 2007. The mean and maximum temperatures varied during the period of evaluation from 23.1 to 23.6 ºC and 29.6 to 32.1 ºC, respectively. The field selected for trial was planted with the CO 86032 variety of sugarcane. The subjects were trained well for the operation of the detrasher. The

Table 1 Average physiological response of selected subjects for the detrashing operation

Detrashers	Heart rate, beats min^{-1}	Energy cost of work, kJ min^{-1}	AWL (35% VO_2 max)	LCP (40 beats min^{-1})
Male subjects				
IISR sugarcane detrasher (SCD_1)	121.54	21.09 (Moderately Heavy)	49.90 (>AWL)	46.34 (>LCP)
OUAT sugarcane detrasher (SCD_2)	117.26	19.79 (Moderately Heavy)	46.84 (>AWL)	43.26 (>LCP)
TNAU sugarcane detrasher (SCD_3)	106.75	16.14 (Moderately Heavy)	38.19 (>AWL)	34.75 (>LCP)
Conventional detrashing (CD)	113.95	18.69 (Moderately Heavy)	44.32 (>AWL)	41.32 (>LCP)
Female subjects				
IISR sugarcane detrasher (SCD_1)	128.56	20.48 (Heavy)	59.42 (>AWL)	54.98 (>LCP)
OUAT sugarcane detrasher (SCD_2)	128.33	20.67 (Heavy)	59.30 (>AWL)	51.11 (>LCP)
TNAU sugarcane detrasher (SCD_3)	124.73	19.67 (Heavy)	57.06 (>AWL)	49.10 (>LCP)
Conventional detrashing (CD)	126.50	20.13 (Heavy)	58.39 (>AWL)	52.65 (>LCP)

trial was conducted between 7:30 AM and 5:00 PM and the subjects were asked to report at the field at 7:00 AM. Each trial started with taking five minutes data for physiological responses of the subjects while resting on a stool under shade. After rest period of half an hour, the selected subjects operated the detrashers. Each trial was conducted for a period of 20 minutes.

Results and Discussion

The physiological response of the subjects for detrashing with selected detarshers are furnished in **Table 1**.

The energy expenditure for the female subjects, varied from 19.67 to 20.67 kJ min^{-1}. Performing the detrashing operation in standing posture, holding the crop in one hand and sliding the tool downward make the detrashing operation tiresome. This justified the grading as "Moderately heavy" for male subjects and. "Heavy" for female subjects.

The mean values of oxygen consumption rate (OCR) in terms of percent VO_2 maximum for male subjects for detrashing with the IISR sugarcane detrasher (SCD_1), OUAT sugarcane detrasher (SCD_2) and TNAU sugarcane detrasher (SCD_3) varied from 38.19 to 49.90 percent of VO_2 maximum. For detrashing of the sugarcane with female subjects, the oxygen consumption rate varied from 57.06 to 59.42 percent of VO_2 maximum. These values were much higher than that of the AWL limit of 35 percent of VO_2 maximum indicating that all the selected detrashers could not be operated continuously for 8 hours without frequent rest periods.

Based on the Corlett and Bishop (1976) regional discomfort scale, the mean values of Body Part Discomfort Score (BPDS) of the male and female subjects for all the selected detrashers are furnished in **Table 2**.

The majority of discomfort experienced by the workers was right shoulder, left shoulder, palms, wrist, left and right elbow and mid back for all the subjects. This discomfort experienced by the subjects was mainly due to a rough handle grip, frequent up and down movement of detrasher and weight of the tool.

Ergonomic Refinements

The TNAU sugarcane detrasher (SCD_3), which registered the lowest value of ergonomic evaluational parameters and highest stripping capacity with minimum damage to sugarcane stalks was chosen and necessary ergonomic refinements were carried out for enhanced comfort of the operator without jeopardizing the efficiency of the detrasher. The ergonomic refinements in the TNAU sugarcane detrasher (SCD_3) are listed below.

- The length of knife supporting stem was reduced from 170 to 130 mm.
- Holes were drilled in the knife supporting stem and knife base for adjusting the stripping length to suit the convenience of the worker.
- The hollow metal tube was replaced with a wooden handle for firm grip while detrashing.
- Weight was reduced from 550 to 390 g.

A comparison of the existing detrasher (SCD) and the ergonomic re-

Table 2 Body Part Discomfort Score of selected subjects for detrashing sugarcane

Detrashers	Body part experiencing pain	Score
I. Male subjects		
SCD_1	Moderate pain in left shoulder and right shoulder, palms and mid back, left and right elbow, left and right wrist.	27.30
SCD_2		24.21
SCD_3		21.13
CD		24.08
II. Female subjects		
SCD_1	Moderate pain in left shoulder and right shoulder, palms and mid back, left and right elbow, left and right wrist.	32.06
SCD_2		28.15
SCD_3		26.20
CD		25.10

Fig. 4 Operational view of sugarcane detrashers

IISR Cane detrasher OUAT cane detrasher TNAU detrasher fined detrasher (ESCD- **Fig. 5**.) was made with the measured parameters to ascertain the improved comfort of the operator. The results are furnished in **Table 3**.

The use of the detrasher with ergonomic refinements enhanced the comfort of the subjects with significant reduction in heart beat and energy expenditure, Acceptable Work Load, limit of continuous performance, Overall Discomfort Rating and Body Part Discomfort Rating for the selected TNAU sugarcane detrasher (SCD).

Ergonomic-costs-benefits

The effectiveness of ergonomic refined detrashers in terms of stripping capacity is furnished in **Table 4**.

The ergonomic refined TNAU sugarcane detrasher, compared to the existing model of TNAU detrasher, showed 5.5-6.6 percent savings in cost and 5.6-5.8 percent savings in time of detrashing. The effectiveness in field capacity for the ergonomic refined detrasher of showed 4.9 percent increase in field capacity for male subjects and 4.8 percent increase for female subjects. Use of the ergonomic refined TNAU detrasher resulted in 13.0 percent and 14.5 percent savings in cost and time, respectively, when compared to conventional hand detrashing.

Table 3 Results of evaluation of ergonomic refined sugarcane detrasher(ESCD)

Ergonomic parameters	Male	Female
HR (beats min^{-1})	101.1 (106.8)	112.8 (124.7)
Energy cost, kJ min^{-1}	14.7 (16.1)	16.5 (19.7)
Energy grade of work	Moderately Heavy	Moderately Heavy
AWL	34.9 (38.2)	47.9 (57.1)
LCP	30.6(34.8)	44.4 (49.1)
ODR	4.3 (5.2)	5.0 (6.1)
BPDS	18.2 (21.1)	21.3 (26.2)

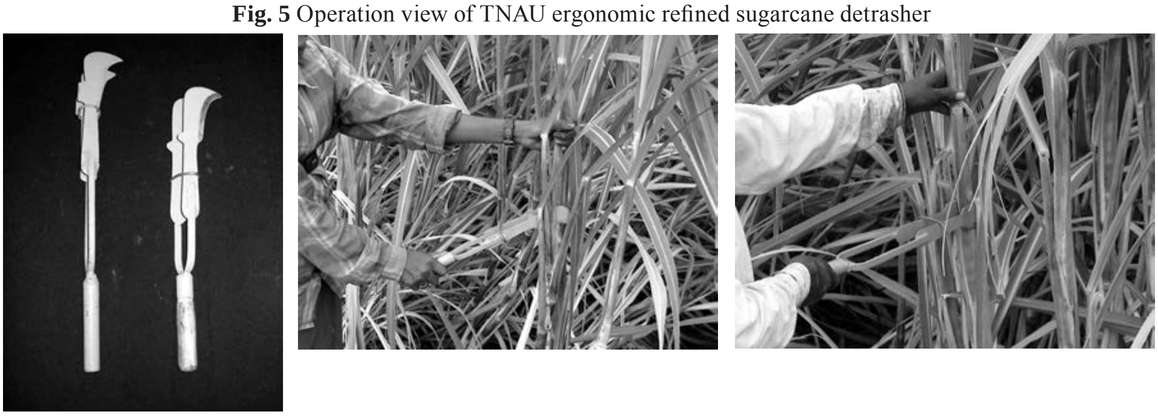
Table 4 Out put of existing and ergonomic refined detrasher

Detrashers	Stripping capacity, kg h^{-1}		Damage caused to sugarcane stalk (%)	
	Male	Female	Male	Female
TNAU sugarcane detrasher (SCD)	117.50	114.25	6.1	4.3
Ergo refined sugarcane detrasher (ESCD)	123.25	119.75	3.5	2.3
Hand detrashing (CD)	110.60	107.00	0.0	0.0
Percent increase in stripping capacity of ESCD when compared to SCD	4.90	4.81	-	-
Percent increase in stripping capacity of ESCD when compared to CD	11.4	11.9	-	-

Conclusion

Sugarcane detrashing is a highly labour intensive operation. Conventional detrashing by hand leads to serious health hazards for the workers. In view of the importance of detrashing operation, mechanical detrashers have been introduced. The available mechanical detrashers were evaluated ergonomically to assess their suitability for men and women farm workers for reduced drudgery and adequate comfort. Twelve male and female subjects were selected for the investigation based on the age and fitness. They were screened for normal health through medical examinations. Ergonomic evaluation was made for the IISR sugarcane detrasher (SCD_1), OUAT sugarcane detrasher (SCD_2) and TNAU sugarcane detrasher (SCD_3) using selected male and female subjects. The TNAU sugarcane detrasher (SCD_3) registered the lowest values of ergonomic param-

Fig. 5 Operation view of TNAU ergonomic refined sugarcane detrasher



eters and highest stripping capacity with no damage to sugarcane stalks. The ergonomic refinements made for the TNAU sugarcane detrasher (SCD_3) were reduction of the length of the knife supporting stem from 170 to 130 mm, addition of a sliding supporting stem and knife base for adjusting the stripping length to suit the convenience of the worker, a wooden handle for a firm grip while detrashing and reduction of weight from 550 to 390 g. The mean value of heart rate, energy cost, oxygen consumption rate in terms of VO_2 maximum and work pulse of male subjects for operation with the ergonomic refined TNAU sugarcane detrasher (ESCD) were 101.12 beats min^{-1}, 14.74 kJ min^{-1}, 34.88 percent of VO_2 maximum and 30.55 beats min^{-1}, respectively. The corresponding values for female subjects were 112.76 beats min^{-1}, 16.52 kJ min^{-1}, 47.91 percent of VO_2 maximum and 44.35 beats min^{-1}. The ergonomic refined TNAU Sugarcane detrasher (ESCD) enhanced the comfort of male subjects with 5.27, 8.67, 12.09, 13.79 and 13.72 percent reduction in heart rate, energy cost, LCP, Overall Discomfort Rating and Body Part Discomfort Score, respectively, when compared to the existing model (SCD). The ergonomic refined TNAU Sugarcane detrasher (ESCD) enhanced the comfort of female subjects with 5.53, 16.01, 9.67, 18.03 and 19.08 percent reduction in heart rate, energy cost, LCP, Overall Discomfort Rating and Body Part Discomfort Score when compared to the existing model (SCD). The ergonomic refined TNAU sugarcane detrasher resulted in 5.5-6.6 percent savings in cost and 5.6-5.8 percent savings in time of detrashing when compared to existing TNAU model detrasher. The effectiveness of ergonomic refinements carried out in the sugarcane detrasher had 4.9 percent increase in field capacity for male subjects and 4.8 percent increase for female subjects. Use of the ergonomic refined TNAU detrasher resulted in 13.0 percent and 14.5 percent saving in cost and time, respectively when compared to conventional hand detrashing.

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■■

Optimization of Barnyard Millet Dehulling Process Using RSM

by

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Abstract

Barnyard millet (Echinochloa colona) is a popular food grain in several parts of India. It is presently being dehulled manually in the absence of a suitable mechanical device. The objective of the present study was to find the optimum mechanical dehulling process parameters of barnyard millet using response surface methodology (RSM). The optimum dehulling efficiency was 87.7 % at 8.6 m/s peripheral drum speed, five passes and 8.4 % d.b. moisture content. A predicted dehulling loss of 6.2 % was observed at optimum conditions. The results of the predicted optimum conditions were validated experimentally. The actual dehulling efficiency and loss at optimum conditions were observed to be 88.2 % and 6.6 %, respectively, which were very close to the predicted values. In the commercial dehulling process, five impellers in series could be used for obtaining the complete dehulled kernel in one pass.

Introduction

Barnyard millet (*Echinochloa colona*) is a commonly grown millet crop in states of Uttaranchal, Tamil Nadu, Andhra Pradesh, Karnataka and Chhattishgarh in India. It is one of the most important millets grown in India. It is popularly known as Madira, Jhungora or Sanwa in different part of India. Under favorable moisture and temperature condition, the grain would ripen within 45 days of sowing (Hulse *et al.*, 1980). Another species of barnyard millet Echinochloa crus-galli, commonly known as Japanese millet, according to archaeological record, was domesticated in Japan about 5,000 years ago and was found in the temperate region of Eurasia (De Wet, 1986). It was harvested as a wild cereal in predynastic Egypt. While the two species are morphologically similar, hybrids between them are sterile; however, crosses of both species with their respective wild relatives are fertile (De Wet, 1986).

Barnyard millet is small grain containing a large proportion (40-45 %) of husk and bran, and requires processing prior to consumption. Barnyard millet is three times richer in minerals as compared to wheat and four times richer in fat, seven times richer in minerals and twice richer in calcium as compared to rice (Gopalan *et al.*, 1997). The grains of barnyard millet are low in phytic acid and rich in iron and calcium (Sampath *et al.*, 1986). The inflorescence produces one fertile and one infertile floret subtended by two unequal glumes. The glumes totally enclose the kernel. The mature pericarp consists of two epidermal

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layers. The cells of inner epidermis are closely compressed against those of the outer part. Barnyard millet has an aleurone layer thought to contain strongly cutinized cell walls (Narayanaswami, 1955; Zee and O'Brein, 1971). In applying dehulling to millets, rice and barley dehullers and polishers have been the major sources of inspiration for further optimized development for grain millets (Hulse *et al.*, 1980; Reichert, 1982). Dehulling of barnyard millet is difficult, as the small size grains are held much more firmly in the glumes and require considerable pressure coupled with repetitive impact, and shear (Singh *et al.*, 2003). The dehulling is conventionally done by manual pounding. The arduous process of traditional dehulling of barnyard millet requires one-hour effort for dehulling of 2-2.5 kg grain (Pushpamma, 1989). The removal of hull from seed greatly improves the appearance of the product (Gopalan and Balasubramanian, 1963; Deshpande *et al.*, 1982) and enhances the digestibility (Heaton, 1973).

Various dehulling methods suitable for use in small-scale milling systems (Reichert & Youngs, 1976; Reichert *et al.*, 1984) were employed in preliminary trials, and it was observed that the dehulling based on impact and shear principle gave better performance for small seeds as compared to abrasive methods. In abrasive methods of dehulling, abrasions and attrition forces crushed the seeds causing a high proportion of dehulling losses (Gupta & Das, 1999). Knowing the above facts, present studies were undertaken to achieve an optimum combination of process variables for complete dehulling of barnyard millet grain with minimum losses.

Materials and methods

Experimental material

Barnyard millet grain (variety: VL-172) were taken from the experimental farm of Vivekananda Institute of Hill Agriculture (ICAR), Almora, India. The seeds were cleaned and graded by a WESTRIP cleaner and grader (type: LA-LS, Denmark) using an appropriate set of sieves to remove foreign material, as well as small and immature grains. Variation in size of seeds may cause low dehulling efficiency (Joshi, 1993). In impact and shear dehulling process, the role of concave clearance is important. The value of minimum concave clearance should be equal to average grain size. Barnyard millet seeds were placed into two grades: (1) A-grade (size > 1.75 mm) and (2) B-grade (size < 1.75 mm). After grading, around 75 percent of the seeds were in A-grade and was used for the present study.

Barnyard millet dehuller and dehulling principle

A small thresher prototype, Vivek thresher-1 was designed and developed (Singh *et al.*, 2002) at Vivekananda Institute of Hill Agriculture (ICAR), Almora, Uttarakhand, India for threshing of millet. This prototype was modified for multiple uses like threshing, dehulling and pearling. This dehulling capacity of the newly developed small prototype was 18-20 kg hulled kernel/h. This small dehuller prototype could also be used for threshing and pearling of finger millets with a capacity 120 and 250 kg/h, respectively. The testing of a small dehuller unit prototype provided important information about the basic dehulling operation, which is required to design commercial scale-dehulling units (Sanders, 1996). The impeller and casing of the dehuller were made of mild steel. Eight canvas strips (fitted with a mild steel flat) 24 mm wide and 450 mm long were radically pitched along the length. A stationary concave, covering 1100 of casing, acted as the impacting surface for the seeds flying from the high speed rotating impeller. In this dehuller, canvas strips were working as abrasive material. The friction force between canvas strip and barnyard millet grain provided the required force on the grain for detaching the hulls (**Fig. 1**).

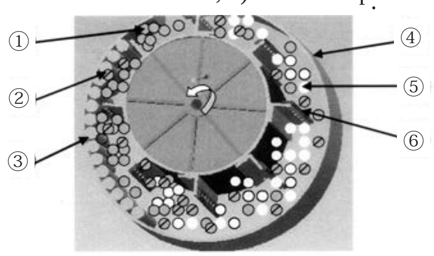
Experimental design

An effort was made by applying the repeated feeding (number of passes) of barnyard millet grain to obtain the complete dehulling without applying any pretreatment. Hence, pretreatment of grain was

Nomenclature

Y_p	predicted value of responses	b_i	linear regression coefficient
X_1	impeller peripheral speed, m/s	b_{ii}	quadratic regression coefficient
X_2	number of passes	b_{ij}	interaction regression coefficient
X_3	moisture content, % dB.	CCRD	central composite rotatable design
x_1	coded value of X_1	η_d	dehulling efficiency, %
x_2	coded value of X_2	γ_{dl}	dehulling loss, %
x_3	coded value of X_3	M_n	mass grain left unhulled, g
b_0	constant	M_l	loss in form of powder and broken grain, g
R^2	coefficient of determination		
		M_t	total mass of grain before dehulling, g

Fig. 1 Impact and shear principle for dehulling of barnyard millet grain: 1) barn yard millet whole grain; 2) split grain due to impact force; 3) concave; 4) Casing; 5) completely dehulled kernel due to shear force; 6) canvas strip.



not considered as a process parameter in the present study. Central composite rotatable experimental design (Hunter, 1959; Lorezen and Anderson, 1993; Rastogi *et al.*, 1998) was made with three independent variables viz., peripheral speed (X_1), number of passes (X_2) and moisture content (X_3). The experimental plan for optimization constituted two dependent variables viz., dehulling efficiency (η_d) and dehulling loss (γ_{dl}). The response surface methodology (RSM) (Myres, 1971; Khuri and Cornell, 1987) was used as a statistical method for analyzing the experimental data and solving the multivariate equations. The RSM is one of the most effective methods for optimization of parameters and many food scientists are frequently using it (Varnalis *et al.*, 2004; Ushakumari *et al.*, 2007; Nath and Chattopadhyay, 2007; Goyal *et al.*, 2008). In RSM, fewer experiments were needed (as compared to a factorial experiment) to evaluate the multiple parameters and their interactions. Therefore, RSM was also used to optimize the process parameters to maximize dehulling efficiency with minimum dehulling loss. Non-linear second order regression equations in the form equation 1 for the responses as a function of coded values (−1.682 to +1.682) of the independent parameters were developed.

$$Y_p = b_0 + \sum_{i=0}^{3} b_i x_i + \sum_{i=1}^{3} b_{ii} x_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} b_{ij} x_i x_j \quad \text{.... (1)}$$

Independent variables, coded values and their real values are given in **Table 1**. A total of twenty experiments were conducted as per CCRD for three independent variables in which six repeated experiments were conducted at a central point (Myres, 1971). In the study, the optimization was carried out using Design Expert 7.0.0 software. For predicting the optimum process parameters, the values of independent variables were kept within the experimental range for maximizing the dehulling efficiency and minimizing dehulling losses.

The dehulling efficiency (η) in percent was calculated using **Eqn. 2** (Sharma and Mandhyan, 1992; Saxena, 1985):

$$\eta_d = (1 - \frac{M_n}{M_t})\,(1 - \frac{M_l}{M_t}) \times 100 \quad \text{.... (2)}$$

Where, η_d = dehulling efficiency, %

M_n = mass of the grain left unhulled, g

M_l = loss in form of powder and broken grain, g

M_t = total mass of grains before

Table 1 Coded values and corresponding real values used in experimentation

Independent variable	Coded level				
	−α (−1.682)	−1	0	+1	+α (+1.682)
Peripheral drum speed, m/s	6.37	7.34	8.76	10.17	11.14
Number of passes	3	4	5	6	7
Moisture content, % dB	6.0	7.22	9.00	10.78	12.00

Table 2 Design of experiment for barnyard millet dehulling with three independent variables in CCRD

Peripheral Speed (X_1) m/s	Number of passes (X_2)	Moisture Content (X_3) %, (d.b.)	Dehulling efficiency %	dehulling loss %
10.17(+1)	4 (−1)	7.22 (−1)	92.00	8.60
7.34 (−1)	4 (−1)	7.22 (−1)	75.00	6.30
8.76 (0)	3 (−1.682)	9.00 (0)	61.00	2.70
8.76 (0)	5 (0)	9.00 (0)	88.00	5.30
10.17 (+1)	4 (−1)	10.78 (+1)	71.00	6.70
10.17 (+1)	6 (+1)	10.78 (+1)	81.00	9.10
7.34 (−1)	6 (+1)	7.22 (−1)	84.00	6.00
8.76 (0)	5 (0)	9.00 (0)	85.00	5.00
7.34 (−1)	6 (+1)	10.78 (+1)	73.00	4.80
8.76 (0)	5 (0)	6.00 (−1.682)	93.00	8.80
10.17 (+1)	6 (+1)	7.22 (−1)	96.00	12.20
8.76 (0)	5 (0)	12.00 (+1.682)	67.00	4.30
8.76 (0)	5 (0)	9.00 (0)	84.00	5.90
8.76 (0)	7 (+1.682)	9.00 (0)	93.00	9.40
11.14 (+1.682)	5 (0)	9.00 (0)	91.00	10.90
7.34 (−1)	4 (-1)	10.78 (+1)	63.00	4.10
8.76 (0)	5 (0)	9.00 (0)	86.00	5.60
6.37 (−1.682)	5 (0)	9.00 (0)	65.00	5.50
8.76 (0)	5 (0)	9.00 (0)	83.00	6.20
8.76 (0)	5 (0)	9.00 (0)	87.00	6.70

Table 3 Analysis of variance sowing the effect of treatment variables as linear terms, quadratic term and interaction on the responses

Source of variation	F_{cal}	
	Dehulling efficiency, %	Dehulling losses, %
Linear		
Peripheral speed (X_1)	24.74***	17.98***
Number of passes (X_2)	59.40***	68.47***
Moisture content (X_3)	60.59***	38.23***
Quadratic		
X_1^2	9.31*	6.12*
X_2^2	11.36*	0.50ns
X_3^2	4.82ns	7.8×10^{-3} ns
Interaction		
$X_1 X_2$	0.32ns	18.21**
$X_1 X_3$	2.18ns	0.35ns
$X_2 X_3$	0.63ns	2.32ns

***Significant (P < 0.001),
**Significant (P < 0.01),
*Significant (P <0.05),
nsNon-significant

dehulling, g

Similarly, dehulling loss (γ_{dl}) in percent was calculated using **Eqn. 3**:

$$\gamma_{dl} = \frac{M_l}{M_t} \times 100 \quad \text{.........................(3)}$$

where, γ_{dl} = dehulling loss, (%)

Results and Discussion

For optimization of independent process parameters, twenty experiments were carried out according to CCRD (**Table 2**). The analysis of the variance for the responses is given in **Table 3**.

Dehulling efficiency

Analysis of variance (ANOVA) for the quadratic model of dehulling efficiency is presented in **Table 3**. F values indicated that the linear terms of independent variables peripheral speed, number of passes and moisture content were significantly affected the dehulling efficiency ($p < 0.001$). However, the quadratic terms of peripheral speed and number of passes affected the dehulling efficiency at the 5 percent level of significance ($p < 0.05$). No significant effect was observed in interaction terms of all variables as well as quadratic term of moisture content ($p > 0.05$). The nonlinear second order regression equation was developed as a function of the coded values of independent variables x_1, x_2 and x_3 for the dependent variables dehulling efficiency. The developed relationship is given in **Eqn. 4**.

$$\eta_d = 85.52 + 6.50x_1 + 7.21x_2 - 7.52x_3 - 0.74x_1x_2 - 1.63x_1x_3 + 1.04x_2x_3 - 2.52x_1^2 - 2.92x_2^2 - 1.82x_3^2 \quad \text{..........(4)}$$

$(R^2 = 0.957)$

The high value of coefficient of determination ($R^2 = 0.957$) indicated that the developed model was correct. The non-significant lack of fit indicated that the regression equation was well fitted for the experimental values. Response surface contours for dehulling efficiency of barnyard millet as a function of impeller peripheral speed, number of passes and moisture content is shown in **Fig. 3**. A gradual increase in dehulling efficiency was observed with an increase of number of passes. A similar trend was observed with impeller peripheral speed. A gradual decrease in dehulling efficiency was observed with decrease in moisture content from 7.22 % to 9 % and rate of decrease was rapid thereafter. Higher dehulling efficiency at low moisture content of seed might be due to fragile nature of seed hulls. Low dehulling efficiency at higher moisture content might be due to excess deformation of seeds, which withstood the impact force from the canvas strip, without splitting the hulls. Similar dehulling trends with moisture content were also observed by Makanjuola (1972) for melon seed, Joshi (1993) for pumpkin seed, Gupta *et al.* (1999) for sunflower seed

Fig. 2 Effect of peripheral speed, number of passes and moisture content on dehulling efficiency: a) effect of peripheral speed and number of passes on dehulling efficiency at 9 % d.b. moisture content; b) effect of moisture content and peripheral speed on dehulling efficiency for five passes; c) effect of moisture content and number of passes on dehulling efficiency at 8.76 m/s speed

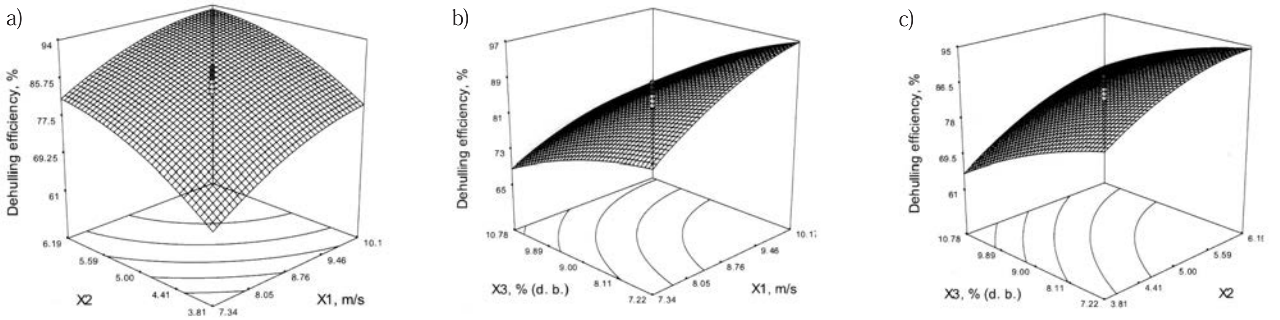
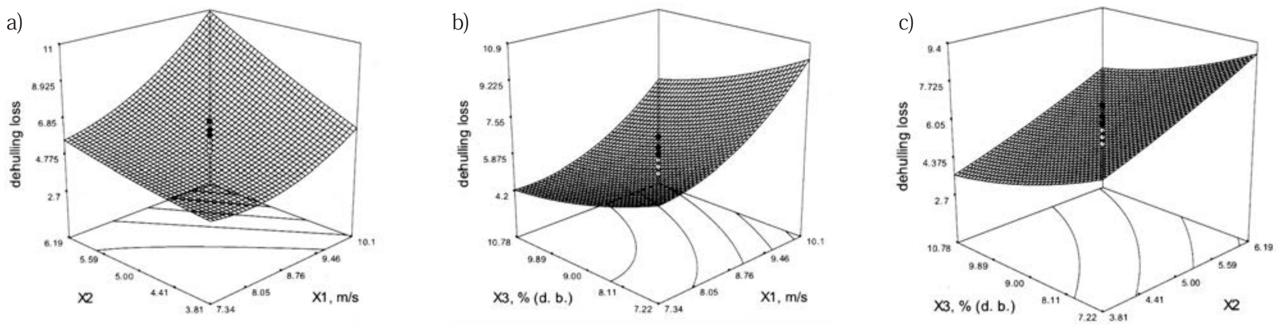


Fig. 3 Effect of peripheral speed, number of passes and moisture content on dehulling loss: (a) effect of peripheral speed and number of passes on dehulling loss at 9 % d.b. moisture content; (b) effect of moisture content and peripheral speed on dehulling loss for five passes; (c) effect of moisture content and number of passes on dehulling loss at 8.76 m/s speed



and Goyal *et al*. (2007) for pigeon pea seed. Around 4-6 percent of the grains remained unhulled even after six passes of repeated dehulling. This might have be due to the presence of immature grain in the lot. Due to very small sized grain, the complete sorting and grading was not possible with available equipment. The sorting of immature grain became easy after dehulling of other bold grains of the lot. Maximum dehulling efficiency of 96 % was observed at 10.17 m/s peripheral speed, six passes and 7.22 % d.b. moisture content (**Table 2**).

Dehulling Loss

ANOVA for the quadratic model of dehulling loss is presented in **Table 3**. F values indicated that the dehulling loss was significantly affected ($p < 0.001$) by linear terms of independent variables. However, no significant effect of number of passes and moisture content was observed on dehulling loss ($p > 0.05$). Impeller peripheral speed was significantly affected by the dehulling loss at the 5 percent level of significance. Interaction terms between peripheral speed and number of passes was significantly affected by the dehulling loss at the 1 percent level of significance ($p < 0.01$). Other interaction terms were not significant ($p > 0.05$). The second order regression equation was developed as a function of coded values of independent variables x_1, x_2 and x_3 for the dependent variable dehulling loss. The developed relation is given **Eqn. 5**.

$$\gamma_{dl} = 5.79 + 6.50x_1 + 7.21x_2 - 7.52x_3 - 0.74x_1x_2 - 0.20x_1x_3 - 0.03x_2x_3 + 0.91x_1^2 + 0.31x_2^2 + 0.32x_3^2 \quad \ldots.(5)$$

$$(R^2 = 0.942)$$

The high value of coefficient of determination (R^2=0.942) indicated that the developed model was adequate. The non-significant lack of fit indicated that the developed second order regression equation was well fitted for experimental data. It is evident from response surface representation (**Figs. 3a, b** and **c**) that the dehulling losses were increased with increases in peripheral speed and number of passes. It indicated that high peripheral speed of impeller produces higher centrifugal force on grain kernel resulting more dehulling loss. Similar results were also observed by Jain (1980) for paddy seed and Joshi (1993) for pumpkin seed. Gradual decrease in dehulling loss was observed with increase in moisture content. Minimum dehulling loss 2.7 % was observed at 8.76 m/s peripheral speed, three passes and 9 % d.b. moisture content (**Table 2**).

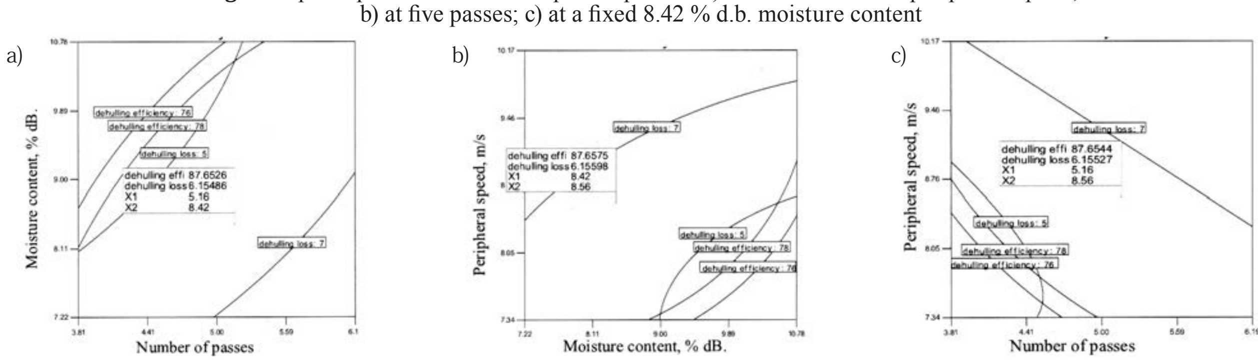
Optimization of Process Variables

The range of optimized responses was achieved numerically by putting the values of process variables within the experimental range. From numerical optimization, the ranges of dehulling efficiency and dehulling loss were 84.57-89.48 % and 5.76-8.76 %, respectively. The same ranges were kept in the graphical method to achieve the more precise optimized values of process variables and their corresponding responses. It is evident from the **Figs. 4 a, b** and **c** that 8.56 m/s peripheral speed, five passes and 8.42 % moisture content were appropriate optimum values of process variables. The corresponding responses of dehulling efficiency and dehulling loss were 87.66 % and 6.16 %, respectively. In order to verify the optimum conditions an experiment was conducted at these conditions. The actual dehulling efficiency and loss obtained with optimum process variables were 88.28 % and 6.59 %, respectively, which were very close to predicted values.

Conclusions

The dehulling process based on impact and shear principle was found successful for dehulling of barnyard millet grains and provided better quality of dehulled kernel. Dehulling efficiency increased as the peripheral speed and number of passes increased. Decrease in dehulling efficiency was observed with the increase in moisture content of the grain. Maximum dehulling efficiency of 96 % was observed at peripheral 10.17 m/s speed, five passes and 7.22 % d.b. moisture content. Dehulling loss increased as the peripheral speed and number of passes increased. Gradual decrease in dehulling loss was observed with

Fig. 4 Superimposed contours of equal responses: a) at a fixed 8.56 m/s peripheral speed; b) at five passes; c) at a fixed 8.42 % d.b. moisture content



increase in moisture content of the grain. Minimum dehulling loss of 2.7 % was observed at 8.76 m/s peripheral speed, three passes and 9 % d.b. moisture content. Optimum dehulling efficiency (88.2 % against predicted 87.66 %) and loss (6.59 % against predicted 6.16 %) were found at peripheral speed 8.56 m/s, five passes and 8.42 % d.b. moisture content. In the commercial dehulling process, five impellers in series can be used for obtaining the completely dehulled kernel in one pass.

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Minimum Tractor Power Requirement for Arable Crop Production Using the Simplex Method: A Case of Barolong Agricultural District of Botswana

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Abstract

Barolong Agricultural District is situated in the Southern Agricultural Region, in Botswana. The district has a high agricultural potential for rainfed farming. The Simplex Method in Tableau Form was used for finding an optimal solution for draught power requirement. The model estimated a 34 kW draught power requirement for the model traditional sector farm. An optimal draught power requirement for the model commercial farm in Barolong District is estimated at 120.0 kW, which is 50 % of the draught power requirement projected by NAMPADD (2000) for the same farm type.

Introduction

Barolong Agricultural District is situated in the Southern Agricultural Region in Botswana. The Southern Agricultural Region is a notable crop production area, comprising of 98,907 ha which constitutes 25.5 % of the total arable land of the country (Agricultural Statistics, 1996). An analysis of the agricultural potential of various districts in Botswana listed the Barolong District as one with the highest potential in the development of rainfed farming (NAMPAAD, 2000). The district comprises of 3,266 ha, which are planted, annually, under the traditional rainfed crop production system. However, field sizes per family average a mere 5.6 ha, which makes it difficult for a family to economically own, operate and maintain an agricultural tractor. Despite the small farm sizes and economic considerations, farmers still own tractors due to social and cultural factors (viz. availability of hired or family labour for field operations, farmer's traditions and skill in animal cultivation, prestige attached to tractor ownership, attitude toward hiring or lending tractors when not in use in their own farms, and mechanical skills) and political factors (viz. land tenure system, credit, tractor hiring scheme, rural employment, agricultural policies, cultural identity, foreign exchange rates, availability of second hand tractors, and marketing and training facilities) (Balasankari and Salokhe, 1999). This results in several problems such as farmers being financially burdened with underutilized tractors, poor maintenance of tractors and hence rendering tractors in a poor operational state.

The commercial sector farms of Barolong District comprise about 5,000 ha of ploughed-and-planted land annually. The commercial farm enterprises are characterized by advanced farming methods, full mechanization of farming activities and an advantage of economies of scale inherent in the use of tractors and implements.

The objective of this study was to develop a model for predicting optimal requirements of agricultural tractor power for the Barolong District.

Methods

The Barolong District lies in the Southern part of Botswana approximately 100 km from the capital city of Gaborone, extending up to the border with the Republic of South Africa (**Fig. 1**).

The research entailed visits to farms in the area and establishment of the amount of available draught power by quantification of the amount of draft power sources which a farm owned. As parameters in this study could be presented as a set of linear equations, the simplex method was used for finding an optimal solution for draught power requirement (Ravindran *et al*., 1987). The decision variables to be determined by the model are the draft power requirements in kilowatts (kW) for each of the farming sectors, namely, the traditional sector and the commercial sector. These are represented by algebraic symbols as follows:

X_1: kilowatts of tractor power required for the model traditional sector farms.

X_2: kilowatts of tractor power required for the model commercial sector farms.

The constraints or restrictions of the model are limited resources, namely available arable land, tractor cost and availability of alternative sources of draft power.

These Limited Resources are Constrained as Follows

Land: The basis of constraining the land is derived from the NAMPAAD (2000) determination of an optimal arable field size and subsequent tractorisation level for Botswana. The optimal arable field size for a progressive traditional sector farmer is 150 ha with a projected requirement of 53 kW tractor power. However, a study by Rebatho (2004) has revealed that a 34 kW tractor, which is available locally, can fulfill all the draught power requirements of this type of farm timeously. The model, therefore, used the 34 kW tractor for the traditional farm power projection instead of the 53 kW tractor. According to the NAMPAAD (2000) report an optimal arable field size of 1,200 ha is projected for a commercial farm with a total tractor power requirement of 239 kW, consisting of 90 and 150 kW tractors. The unitary values of land, in ha/kW tractor power becomes 4.4 ha/kW for the traditional sector farms, and 14.5 ha/kW for the commercial farms. The constraint of the limited land resource is represented in the form of an algebraic equation as follows:

$$4.4X_1 + 14.5X_2 \leq 1350 \text{ .... (1)}$$

The total land requirement is the sum of the amount of projected arable field size for the traditional and commercial sector farms. This is the optimal field size requirement contrary to the current establishment where some traditional farms comprise as low as 5 ha fields.

Tractor cost: This is constrained on the basis of local tractor market price per kW of tractor power for each of the two farming system types. The traditional sector farm is projected to require a 34 kW tractor which locally costs U.S $19,519.00. The per kW tractor power cost becomes U.S $574.00. This is cost price for a brand new tractor, contrary to the observation by Rebatho (2004) that none of the traditional sector farms owned a brand new tractor. The model, therefore, reduced the cost of a tractor for this type of farm to half the cost for a new tractor. The per kW tractor power cost used in the model then becomes U.S. $287.00. The rationale for this costing is that the tractor market in Botswana offers a 1 year warranty on a brand new tractor, and 6 months on a fully refurbished tractor. Since none of the traditional sector farms in the study area had ever bought a brand new tractor for their farming operations, the model proposed that an optimal expenditure on a tractor will be half the cost of a brand new tractor, spent on a fully refurbished tractor with a warranty of 6 months.

Commercial farms are operated as a profit oriented business entity and, despite the fact that NAMPAAD report of 2000 projected a draught power requirement of a 149 kW tractor and an 89 kW tractor, the study by Rebatho (2004) revealed that the same operations are done timeously using a 49 kW four wheel drive tractor, which costs U.S $ 27,260.00 and a 34 kW tractor. The model therefore used a total tractor power projection of 83 kW for the commercial farm type, which resulted in a per kW tractor power cost of U.S $564.00.

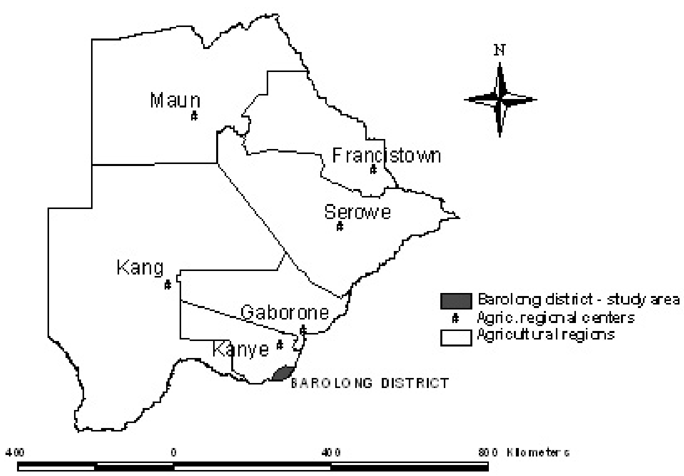
The constraint on tractor cost is computed by summing the tractor power cost per kW for the two farming types.

It is represented in the form of an algebraic equation as follows:

$$287X_1 + 564X_2 \geq 56,570 \text{ .... (2)}$$

This is the minimum budget amount for tractor purchase for the traditional and commercial sector

Fig. 1 Crop Production Regional Boundaries of Botswana



farms. Farmers, especially commercial ones, can exceed this minimum subject to profitability of their enterprises.

Availability of alternative sources of draft power, is constrained on the basis that oxen, cows, tollies, horses and donkeys in Barolong District, which constitute 11,320 kW (Agricultural Statistics, 2002) can be alternative sources of draft power for the traditional farm sector. A traditional sector farmer can opt to use animal draught power and therefore decide against acquiring tractor power, and, therefore, poses a limitation on the number of tractors that can be acquired within the district. The district comprises 3,266 ha of traditional farms, with an alternative draught power of 11,320 kW. The available alternative draught power for a model traditional farm of 150 ha is therefore 520 kW which converts to 15.29 kW/kW tractor power.

The available tractor power for the traditional farm sector can be the alternative source of draft power for the commercial farm sector. The 34 kW tractor power projected for the traditional farm becomes the alternative draught power for the commercial farm, which converts to 0.41 kW per kW tractor power.

The available tractor power for the commercial farm sector can not be an alternative source of power for the traditional farm sector because of the disparity of income generated in commercial farms which can not be matched by that in the traditional farm sector. Therefore, draft power can only be substituted for a more income generating operation. The alternative sources of draught power are thus constrained as per the NAMPAAD (2000) farm power projections.

The constraint is represented in the form of an algebraic equation as follows:

$$15.29X_1 + 0.41X_2 \leq 554 \quad (3)$$

The total of available alternative power sources can not exceed the maximum amount of available equivalent draft power as derived from oxen, cows, tollies, horses and donkeys for the traditional sector farms and tractor power for the traditional farm sector, which is an alternative power source for the commercial sector.

The model is represented as shown in **Table 1**.

The objective of the function is to optimize the tractor power requirements for the two farming types. Optimization in this regard will necessitate minimization, so that minimal tractor power requirements are determined. This is represented in the form of an algebraic equation as follows:

$$Z = 34X_1 + 83X_2 \quad (4)$$

Subject to the constraints:

$$4.4X_1 + 14.5X_2 \leq 1350$$
$$287X_1 + 564X_2 \geq 56,570$$
$$15.29X_1 + 0.41X_2 \leq 554$$
$X_1 \geq 0$ and $X_2 \geq 0$

Eqn.4 with its constraints is a General Linear Programme Model which has to be converted to a problem in Standard Form, requiring that all the inequality constraints be equality equations. This is done by introducing new slack variables.

The new constraints on **Eqn.4** become:

$$4.4X_1 + 14.5X_2 + X_3 = 1350 \quad (5)$$
$$287X_1 + 564X_2 + X_4 = 56570 \quad (6)$$
$$15.29X_1 + 0.41X_2 + X_5 = 554 \quad (7)$$
$X_1 \geq 0$, $X_2 \geq 0$, $X_3 \geq 0$, $X_4 \geq 0$, and $X_5 \geq 0$,

where X_3, X_4 and X_5 are basic variables in **Eqns. 5, 6** and **7** respectively.

Table 1 Linear Programming Model

	MODEL	
	TF	CF
Land, Ha per kW	4.4	14.5
Tractor Cost, U.S $/kW	287	564
Alternative Draft Power, kW/kW	15.29	0.41
Tractor Power Requirement, kW	34	83

TF = Traditional Farm, CF = Commercial Farm

Table 2 Minimum ratio rule

Basic Variable	Upper Limit on X_2
X_3	1,350 / 14.5 = 93.1
X_4	56,570 / 564 = 100.3
X_5	554 / 0.41 = 1351.2

Tableau 1 The initial feasible solution in Tableau Form

	C_j	34	238	1	1	1	
C_B	Basis	X_1	X_2	X_3	X_4	X_5	Constants
1	X_3	4.40	14.50	1.00	0.00	0.00	1,350.00
1	X_4	287.00	564.00	0.00	1.00	0.00	56,570.00
1	X_5	15.29	0.41	0.00	0.00	1.00	554.00
	$\bar{C}$ row	−272.69	−495.91	0.00	0.00	0.00	Z = 58,474.00

Tableau 2 Basic Feasible Solution in Tableau Form

	C_j	34	83	1	1	1	
C_B	Basis	X_1	X_2	X_3	X_4	X_5	Constants
83	X_3	0.30	1.00	0.07	0.00	0.00	93.10
1	X_2	115.86	0.00	-38.90	1.00	0.00	4,059.66
1	X_5	15.17	0.00	0.03	0.00	1.00	515.83
	$\bar{C}$ row	−121.93	0.00	34.06	0.00	0.00	Z = 4,668.59

The Standard Form Model then becomes:

$$Z = 34X_1 + 83X_2 + X_3 + X_4 + X_5 \quad \text{.......................................(8)}$$

Optimal tractor power requirements are determined by minimizing the model in **Eqn.8**, and it is solved using the simplex method in tableau form.

The initial basic feasible solution as a canonical system is:

$$Z = 34(0) + 83(0) + 1350 + 56570 + 554 = 58{,}474 \text{ kW} \quad ..(9)$$

The initial feasible solution is represented in Tableau form as shown in **Tableau 1**.

The negative values of $\bar{C}_1$ and $\bar{C}_2$ indicate that the objective function can further be minimized, therefore the solution is not optimal. The fact that the value of C_2 is the smallest implies that X_2 contributes on a per unit basis to a larger decrease of the objective function, Z value than X_1.

The minimum ratio rule as shown in **Table 3** is used to decide which basic variable is to be replaced.

The minimum value in **Table 2** is observed on row 1, for basic variable X_3, which implies that when non-basic variable X_2 is reduced to its minimum of -495.91 the basic variable in the pivot row X_3 reduces to zero.

The new basis contains X_2, X_4 and X_5 as basic variables. The new canonical system is obtained by performing a pivot operation as follows:

1) Divide pivot row by 14.50 to make the coefficient of X_2 unity.
2) Multiply pivot row by -38.90 and add it to the second row to eliminate X_2.
3) Multiply pivot row by -0.03 and add it to the third row to eliminate X_2.

The pivot operation gives the following feasible solution in **Tableau 2**.

The negative value of $\bar{C}_1$ indicates that the objective function can further be minimized, therefore the solution is not optimal. The minimum ratio rule as shown in **Table 3** is used to decide which basic variable is to be replaced. The minimum value in **Table 3** is observed on row 3, for basic variable X_5, which implies that when non-basic variable X_1 is reduced to its minimum of -121.93 the basic variable in the pivot row X_5 reduces to zero. The new basis contains X_1, X_2 and X_3 as basic variables. The new canonical system is obtained by performing a pivot operation as follows:

i) Divide pivot row by 15.17 to make the coefficient of X_1 unity.
ii) Multiply pivot row by -7.64 and add it to the second row to eliminate X_1.
iii) Multiply pivot row by -0.02 and add it to the first row to eliminate X_1.

The pivot operation gives the feasible solution in **Tableau 3**.

The zero values in the $\bar{C}$ row indicate that the objective function cannot be minimized further, therefore the solution is optimal.

An optimal solution is given by $X_1 = 34$ *and* $X_2 = 120.04$ *kW.*

Assumptions of the Model

The following assumptions were made in using the model:

A model traditional sector farm of 150 ha, is characterized by rainfed crop production activities, whereby draught power lies idle during the off-season;

A model commercial farm of 1,200 ha is characterized by a planned crop production routine, whereby there is activity on the farm all year round, and hence draught power is utilized all year round;

The model assumed that entrepreneurs for the commercial farm sector will buy only new tractors, while those for the traditional farms can buy used tractors at half the price of a new tractor;

There is no other factor which determines tractor requirement for arable crop production in Barolong District except the three variables, namely, land availability, tractor cost and availability of alternative sources of draught power.

Table 3 Minimum ratio rule row number

Basic Variable	Upper Limit on X_2
X_3	93.10 / 0.30 = 310.33
X_2	4,059.66 / 115.86 = 35.04
X_5	515.83 / 15.17 = 34.00

Tableau 3 Basic Feasible Solution in Tableau Form

	C_j	34	83	1	1	1	
C_B	Basis	X_1	X_2	X_3	X_4	X_5	Constants
1	X_3	0.00	1.00	0.07	0.00	−0.02	82.90
83	X_2	0.00	0.00	−38.90	1.00	−7.64	120.04
34	X_5	1.00	0.00	0.00	0.00	0.07	34.00
	$\bar{C}$ row	0.00	82.00	3,229.63			Z = 236.94

Results and Discussion

The results show that an optimal tractor size for the Barolong Agricultural District's traditional sector farm is 34 kW. This is consistent with the findings by Rebatho (2004). A draught power requirement of 120.04 kW is projected by the model for the model commercial sector farm while NAMPAADD (2000) projected a total draught power requirement of 238.6 kW for the same type of farm. The minimum draught power projected by the model is

50 % less than the projection by NAMPAADD (2000). The minimum draught power requirement as projected by the model is, therefore, a guide on the minimum draught power investment the commercial sector farmer can initially invest in with the objective of ultimately attaining a 238.6 kW tractor draught power as projected by NAMPAADD 2000.

Conclusions

The model projects that a traditional sector farm must own a minimum of 34 kW tractor draught power, while the commercial sector farm must own a minimum of 120.04 kW of tractor draught power for arable purposes, in the Barolong Agricultural District of Botswana.

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NEWS

6th International CIGR Technical Symposium

TOWARDS A SUSTAINABLE FOOD CHAIN

Food Process, Bioprocessing and Food Quality Management 18th – 20th April 2011 Nantes, FRANCE

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Parallel sessions on ▪Postharvest technology ▪Preservation, storage, and distribution ▪Processing equipment and technologies for agricultural and food products ▪Innovative and non-thermal technologies ▪Properties of agricultural products & foods ▪Engineering for food safety and security ▪Foods and sensors, sensing technology ▪Mathematical modeling and simulation ▪Process control ▪Product monitoring in the supply chain ▪Energy efficiency and environmental friendliness of agri-food chain

CIGR – Section 6

CIGR Section VI (Postharvest Technology and Process Engineering) deals with the engineering principles and technologies in postharvest and processing of agri-food products. It is devoted to follow the trends, promote the advancement and enhance the dissemination and transfer of technology in postharvest and processing at a global scale.

To fulfill better its missions, Section VI of CIGR is organizing the 6th International Technical Symposium: Toward a Sustainable Food Chain in Nantes, France.

The event follows 5 previous similar events held in each continent, demonstrating the international profile of CIGR: China (2004), Poland (2006), Italy (2007), Brazil (2008), and Germany (2009). As previous in Symposiums, selected papers presented at this Symposiums will be published in a special issue of Food and Bioprocess Technology – An International Journal published by Springer and indexed by SCI.

Program

Thursday 14th – Friday 15th April
(in DIJON – France)
Pre-Symposium Workshop on Food Safety
http://www.welience-training.com

Sunday, 17th April, Registration–welcome (16:00–19:00)

Monday, 18th April, Registration–Technical + poster sessions–end of day cocktail party (get–together)

Tuesday, 19th April, Technical + poster sessions; Evening: Gala dinner–cruise on the Erdre River

Wendnesday, 20th April, Special Session: **Sustainability of the Food Chain-Food Industry and Food for Life** 9:00-13:00 (English & French)

Agenda

Important Dates

15/09/2010 Abstract submission deadline
15/11/2010 Confirmation about abstract
15/12/2010 Early bird payment deadline
08/02/2011 Registration due deadline
18/02/2011 Full paper for CD proceedings

Ergonomic Evaluation of Male and Female Operators during Weeding Operation

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Abstract

All agricultural equipment is either operated or controlled by human workers and the equipment requires skill, effort and correct speed. The estimated values of energy expended can be used to define limits of human effort for various agricultural operations. The performance of the operator in different field operations can be assessed on the basis of the physiological responses. The estimation of energy expenditure rate (EER) by measuring the oxygen consumption rate (OCR) is a fairly accurate and acceptable method. The Morgan Oxylog II Apparatus recorded OCR during field operations. Oxylog can be easily mounted on the back of the operator and the oxygen consumed by the operator during particular operations in the field can be recorded and data downloaded to a PC for analysis and calculation.

In the Saurashtra region, weeding by sickle and with a manual weeder is a common practice of the farmers. Four male and four female workers took part in this study. Subjects were acclimatized for the experimental protocol. Heart rate and oxygen consumption rate of male workers were measured. The physiological cost of male and female subjects was worked out on the basis of OCR and was 15.87, 15.87, 16.08 and 15.87 kJ min^{-1} and 8.14, 8.35, 8.35 and 8.35 kJ min^{-1} for subjects 1, 2, 3 and 4, respectively. Similarly, physiological cost was worked out for female workers during weeding by manual weeder and was 13.57, 14.41, 14.20 and 14.41 kJ min^{-1} for subjects 1, 2, 3 and 4, respectively.

Introduction

More and more hand tools, implements and machines are being used in Indian agriculture for performing various agricultural operations. All the equipment is either operated or controlled by human workers. The time has come when Indian women are also operating the tractor. They are devoting many hours in the field but their work is not given due credit. While being an integral and crucial part of agricultural systems, women do not have access to new technologies that could save a tremendous amount of time and back breaking labour (Cherian *et al.*, 2000). Hence, to achieve better efficiency of performance and more human comfort, it is necessary to design equipment within the capabilities and limitations of the operator. Earlier studies reported measurement of different physiological responses like heart rate, oxygen consumption and energy expenditure of the agricultural workers for different activities, tools and implements. Heart rate bears a linear relationship with the intensity of physical exercise and oxygen consumption, especially if the steady state is reached (Karporich, 1966; Le Blanc, 1957; Suggs and Splinter, 1961).

A heart rate monitor can measure instantaneous heart rate continuously over a period of time under field conditions and right at the place of work in the field. Therefore, several research workers have employed this technique as a reliable index for energy requirement, postural studies and for other working environment parameters (Berger, 1967). Morehouse and Miller (1963) concluded that a period of 3-5 min is considered suitable for pulse rate to stabilize depending upon nature of exercise. Tomlinson (1970) reported that a rapid increase occurs in the HR at the start of work and the highest takes place within the first 15 seconds of increase and gradually becomes constant. Gite (1993) carried out an ergonomic evaluation of six manual weeders. The mean OCR during the operation varied from 0.50 to 0.63 l min^{-1} for different weeders. The postural discomfort varied from 3.0 to 5.1 on an 8-point scale (0-No discomfort, 8-Extreme discomfort) for a 15 min operation of each weeder.

Pawar (1978) investigated the amount of energy exerted by the operator during operations like seedbed preparation and puddling. Puddling operation required 147.31 -188.70 kg min^{-1} of human effort when performed with two different power tillers. The tillage operation required human effort in the range of 131.22-188.70 kg min^{-1} at different forward speeds. Both the puddling and tillage operations were observed to be moderately heavy. Saha *et al.* (1979) reported that an acceptable workload for the average young Indian worker varies between 30-40 % of an individual maximum aerobic power under comfortable environment conditions. The corresponding heart rate and energy expenditure reported by the author were 110-beats min^{-1} and 18 kJ min^{-1}, respectively.

Materials and Methods

Weeding by sickle and manual weeder was studied at the vegetable research station, Junagadh, in a field of chilli with row-to-row spacing of 0.60 m. Four male and four female subjects in the age group of 30 to 50 years were selected at random for weeding by sickle (**Figs. 1a** and **1b**). Four female subjects were randomly selected for weeding by manual weeder (**Fig. 2**), since, generally, women agricultural workers in the Saurashtra region are employed on the farm for agricultural work such as weeding and harvesting. Trials were conducted for each subject. Each trial by each subject was of 15 min duration.

The subject was made well acquainted with the experimental protocol to achieve their full cooperation and to maintain the uniformity in the measurement. Initial heart rate (HR) was noted in the position. After the start of work, 5 min was taken as the warm-up time to adjust the metabolic activities of the operator during work and at rest. HR and OCR were measured at one-minute intervals after five minutes from the beginning of work. The same process was repeated to get three sets of readings and the average of three sets was used to maintain the accuracy. Energy expenditure rate (EER) is a function of HR (Sengupta, *et al.*, 1979). Here EER was calculated by OCR for more accuracy. The average HR and OCR was calculated each minute for the given operation from the 6th to 15th min. After 15 min of work the subject was asked to stop and rest until the heart rate returned to normal.

A Polar heart rate monitor with computer interface was used for measurement of HR. Oxygen consumption was recorded using Morgan Oxylog-II apparatus. The recorded data of the heart rate as well as oxygen consumption rate were downloaded to a PC for further analysis and estimation of energy expenditure rate. The ambient temperature in the field was 35.7 ºC.

Results and Discussion

Physiological Study During Weeding by Sickle

The data recorded for HR and OCR during the operation of the sickle by male and female operators are shown in **Tables 1** and **2**.

The average heart rate for male subjects during operation of the

Fig.1 Weeding by sickle for physiological study (a) Male worker (b) Female worker

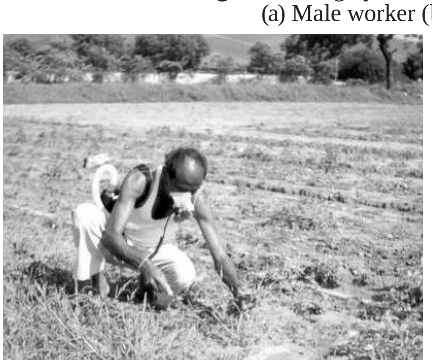
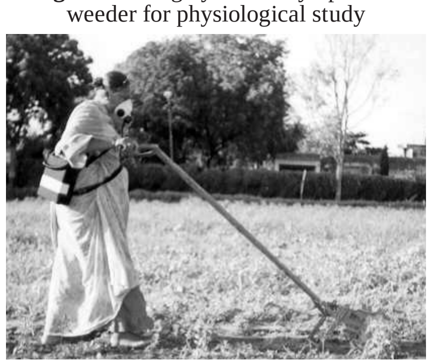


Fig.2 Weeding by manually operated weeder for physiological study



sickle was 129.1, 129.3, 129.2 and 129.2 beats min^{-1} for subject 1, 2, 3 and 4, respectively. For the four female subjects the heart rate was 121.1, 120.6, 121.3 and 121.2 beats min^{-1}, respectively. The oxygen consumption rate was 0.76, 0.76, 0.77 and 0.76 l min^{-1} and 0.39, 0.40, 0.4 and 0.40 l min^{-1} for subjects 1, 2, 3 and 4, respectively. On the basis of oxygen consumption rate the physiological cost of the weeding operation by sickle was 15.87, 15.87, 16.08 and 15.87 kJ min^{-1} for male subjects 1, 2, 3 and 4, respectively, and 8.14, 8.35, 8.35 and 8.35 kJ min^{-1} for female subjects 1, 2, 3 and 4, respectively.

Table 1 Heart rate and oxygen consumption rate of male workers during weeding operation by manual operated sickle

Male	S1	S2	S3	S4	S1	S2	S3	S4
6	133	131	130	131	0.72	0.75	0.73	0.74
7	129	127	129	128	0.75	0.73	0.74	0.72
8	128	128	127	127	0.72	0.73	0.76	0.75
9	127	129	128	128	0.74	0.75	0.73	0.73
10	127	129	129	128	0.80	0.78	0.80	0.81
11	127	129	130	130	0.69	0.76	0.75	0.79
12	126	129	129	129	0.73	0.73	0.78	0.71
13	135	130	130	131	0.82	0.80	0.81	0.80
14	133	131	131	129	0.80	0.80	0.82	0.81
15	128	129	129	130	0.79	0.78	0.79	0.78
Avg	129.1	129.3	129.2	129.2	0.76	0.76	0.77	0.76

Time min Heart rate, beats min^{-1}, Oxygen consumption rate, l min^{-1}

Table 2 Heart rate and oxygen consumption rate of female workers during weeding operation by manual operated sickle

Female	S1	S2	S3	S4	S1	S2	S3	S4
6	122	120	120	122	0.39	0.40	0.40	0.41
7	119	121	121	121	0.38	0.39	0.42	0.39
8	125	120	124	122	0.40	0.42	0.41	0.41
9	121	121	122	120	0.44	0.40	0.42	0.41
10	129	125	125	124	0.37	0.39	0.39	0.39
11	118	119	119	120	0.38	0.39	0.42	0.42
12	117	120	119	119	0.37	0.41	0.39	0.39
13	119	119	120	121	0.35	0.39	0.38	0.40
14	121	120	122	122	0.40	0.42	0.41	0.41
15	120	121	121	121	0.38	0.39	0.39	0.39
Avg	121.1	120.6	121.3	121.2	0.39	0.40	0.40	0.40

Time min Heart rate, beats min^{-1}, Oxygen consumption rate, l min^{-1}

Table 3 Heart rate and oxygen consumption rate of female workers during weeding operation by manual weeder

Female	S1	S2	S3	S4	S1	S2	S3	S4
6	151	152	151	154	0.71	0.70	0.69	0.70
7	158	156	153	157	0.64	0.68	0.69	0.69
8	160	158	157	159	0.67	0.69	0.70	0.69
9	157	156	158	158	0.72	0.70	0.71	0.70
10	159	158	156	159	0.67	0.69	0.69	0.68
11	162	160	161	160	0.59	0.68	0.68	0.67
12	161	160	160	162	0.62	0.69	0.67	0.69
13	160	161	160	158	0.65	0.69	0.66	0.67
14	157	158	159	159	0.63	0.68	0.69	0.69
15	153	155	158	158	0.64	0.70	0.66	0.67
Avg	157.8	157.4	157.3	158.4	0.65	0.69	0.68	0.69

Time min Heart rate, beats min^{-1}, Oxygen consumption rate, l min^{-1}

Physiological Study during Weeding by Manual Weeder

Generally women agricultural workers in the Saurashtra region are employed on the farm for agricultural work such as weeding and harvesting. Therefore, the woman operator was used with the weeder. The data collected for heart rate and oxygen consumption rate are shown in **Table 3**. The average heart rate during weeding by female subjects 1, 2, 3 and 4 for the manually operated weeder was 157.8, 157.4, 157.3 and 158.4 beats min^{-1}, respectively. On the basis of oxygen consumption rate, the physiological cost of female subjects 1, 2, 3 and 4 was 0.65, 0.69, 0.68 and 0.69 l min^{-1}, respectively. Therefore, it can be stated that weeding by sickle and weeding by weeder comes under moderately light and moderately heavy work, respectively.

Conclusions

Physiological cost for workers was determined on the basis of OCR and was found to be 15.87, 15.87, 16.08 and 15.87 kJ min^{-1} for male subjects 1, 2, 3 and 4, respectively, and 8.14, 8.35, 8.35 and 8.35 kJ min^{-1} for female subjects 1, 2, 3 and 4, respectively, while weeding by sickle. Physiological cost of weeding by manual weeder operated by female subjects 1, 2, 3 and 4 was 0.65, 0.69, 0.68 and 0.69 l min^{-1}, respectively. On the basis of scaling of workload, weeding by sickle and weeding by weeder comes under moderately light and moderately heavy work, respectively.

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Development of Automatic Chemical Sprayer

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Abstract

The advent of the computer and camera vision has given a valuable research tool for the development of automation systems to increase mechanization technology in the agriculture sector. Application of the computer for the real-time weedicide sprayer has been one of the outstanding developments in Malaysian agriculture especially in overcoming labor shortages in oil palm plantations. A commercial sprayer was modified with a guided automation system with the web camera to detect the presence of weeds. The sprayer was installed with a web camera, portable computer, ICPCON I-7042 and SST-2400 radio modem. Module ICPCON I-7042 and a radio modem SST-2400 were selected as the data acquisition and control. The radio modem, that was set as receiver, received the signals and transferred them to the ICP module I-7042 via RS-485 bus. The ICPCON I-7042 and SST-2400 were later replaced with a locally made 'parallel port controller board'. The purpose of this study was to develop an automated sprayer that used camera vision for the application of chemicals on an autonomous all terrain vehicle (ATV). The objective for this project was to detect the presence of weeds in real-time and spray the chemicals precisely to eradicate the weeds. The real-time weedicide sprayer was designed to reduce wastage, labor and cost and to control environmental hazards.

Introduction

Presently, the Malaysian agricultural sector is facing serious problems due to the shortage of skilled agricultural workers. The production of our agricultural commodities and our primary commodities, namely oil palm, rubber and cocoa, is very labor intensive. The impact of industrialization in Malaysia causes the transfer of resources such as manpower, land and capital out of the agricultural sector. While the introduction of mechanization and the application of engineering technologies towards agriculture is low, mechanization is considered as the crucial factor in industrialization process. Mechanization has released agricultural workers to industries, thus, contributing to the nation's industrial expansion. Mechanization of agriculture has two main objectives; 1 to increase the productivity per agricultural worker and 2 to change the character of farm work, making it less arduous and more attractive.

Weeds compete with the crop for water, light, nutrients and space, and, therefore, reduce crop yields and affect the efficient use of machinery. Manual weeding is a laborious operation, thus, mechanical or chemical applications are the best options. The most widely used method for weed control in an oil palm plantation is to use agricultural chemicals (herbicides and fertilizer products). The chemical sprayer is the most popular method to eradicate weeds in Malaysia but has caused hazardous and harmful effects to the environment, crops and humans. Most plantations (oil palm, rubber and cocoa) adopt manually sprayed herbicides or weedicides as their weeding strategy which is known to be inefficient, labor intensive and also hazardous to the environment and plantation workers. Manual labors are still being used to perform tedious weeding activities in the plantation field. There is a shortage of labor to carry out manual spraying using the knapsack sprayer. Locating the exact position of the weed is one of the most important tasks needed to further automate farming.

Weed detection at the time of spraying could be very valuable for reducing chemical costs and reducing environmental contamination. Only with the technology to locate individual plants, can "smart" field machinery be developed to automatically and precisely perform treatments such as weeding and chemical application (Wan Ishak, 2007). Many researchers have attempted to detect weeds in crop fields with machine vision system (Choo, C. H. *et al.*, 1990 and Tillet, N. D., 1991). A real-time automated sprayer has been introduced to the Malaysian farmers to locate, in the real time environment, the existence and intensity of weeds and to spray weedicides automatically and precisely. Vision is a most powerful and complicated sense. It provides us with a remarkable amount of information of our surroundings and enables us to interact intelligently with the environment. Research on machine vision has been applied to agriculture to identify weeds. Many researchers have tried various image processing methods in different environments. However, most of the work has been done indoors. Most of the work in outdoor lighting conditions has been associated with robotic fruit harvesting (Kondo and Ting, 1998). Variation of the outdoor daylight environment changes the light intensity, thus, changes the color of the agriculture products. To avoid the variations of light intensity of the outdoor environment, the RGB values of the weeds are captured in real time. These values are saved and used as a reference color. During the spraying operation, the on-line cameras capture the image of the weeds and compare with the reference color that was captured on real-time basis. The spray nozzle open or close based on the presence and intensity of weeds captured on the camera. This on/off function will reduce the volume to be sprayed and, therefore, help to reduce hazards to the environment as well as production cost. The advent of the computer and camera vision is a valuable tool for the researcher to develop automation systems to increase mechanization technology in the agriculture sector.

Methodology

Development of Controller

Fig. 1 shows installation and setup of the automatic weedicide chemical sprayer. The sprayer was installed with the web camera, portable computer, ICPCON I-7042 and SST-2400 radio modem. These were selected as the data acquisition and control. The radio modem, set as a receiver, received the signals and transferred them to the ICP modules (I-7042) via a RS-485 bus. The ICPCON I-7042 and SST-2400 was later replaced with a locally made 'parallel port controller board'. The SST-2400 radio modem was the 'heart' of the PC-based control system. It provided digital input/output and other functions. It handled the signal transfer from the computer to the mover. The radio modem communicated with the computer by using the RS-232 serial port. The radio modem receiver received the signals and transferred them to the ICP Modules I-87057 via RS-485 bus. DO0 from the ICPCON I-87057 was connected to the Normally Open (NO) solenoid valve to the sprayer tank for flow by-pass action. When the output signal was activated, the relay energized and caused electrical energy to flow to the NO solenoid valve and automatically closed the valve. DO1, DO2 and DO3 from the ICPCON I-87057 were connected to the Normally Closed (NC) solenoid valve for nozzle 1, nozzle 2 and nozzle 3, respectively. When the output signal was activated, the relay energized and caused the electrical supply to flow to the NC solenoid valve and automatically opened the valve to operate the nozzle.

Information in **Table 1** is useful in determining the task for each output channel of the ICPCON I-87057. The modules are programmed by using Visual Basic programming language. The software packages for ICPCON I-7000/8000/87K series module used were I-7000/8000 Utility and NAP 7000X. **Table 1** shows the output signal assigned for the ICPCON I-87057. The source code is written by referring to the information in **Table 1**. This information is useful in determining the task for each input and output channels of the ICPCON I-87057. It also helps in the troubleshooting process when the task is not done according to user command.

Development of Vision System

Two PC web cameras were installed on the left and right side of the boom sprayer. The camera on the left will display the image of the weeds to be sprayed by nozzles 1, 2 and 3 while the camera on the right will display the image of the weeds for nozzles 4, 5 and 6. Each camera will cover three segmented display images for the three specific areas of applications from the three

Fig.1 Automatic Sprayer Installed on the Polaris ATP500

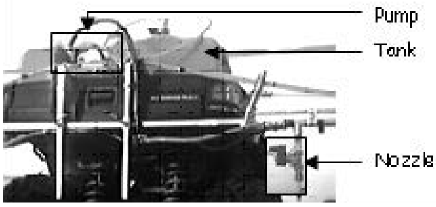


Table 1 Output assigning of the ICPCON I-87057

Module	Channel	Description
I-87057	DO0	Bypass
	DO1	Nozzle1
	DO2	Nozzle2
	DO3	Nozzle3
	DO4	Engine (Ignition)
	DO5	Motor (Forward)
	DO6	Motor (Reverse)

nozzles. These cameras will control the area of spraying. The respective nozzles will trigger the spray solution when the weeds with green color appear at their respective area. Selective spraying can be carried out whereby the appropriate nozzle will spray the chemical in the presence of the weeds. The nozzle will be closed when the green color of weeds failed to be detected.

This spraying system uses USB webcam to capture the images of the weeds. The image is sampled into a rectangular array of pixels. Each pixel has x and y coordinates that correspond to its location within the images. **Fig. 2** shows a sample of image captured using the USB web camera. The x coordinate is the pixel's horizontal location, the y coordinate is the pixel's vertical location. The coordinates (x, y) identify the intensity or gray level of the images of the point. The gray level images are then calculated by linear combination of an RGB vector of the color images. The Visual Basic program (VB) reads the RGB values of each pixels of the total area of the image. The RGB color pixels range from 0 to 255. The basic API pixel routines obtained from the VB programming language will be used to read the RGB value, pixel by pixel, of the image. The function read one by one from first pixel to the end of pixel coordinate. Each coordinate will extract the RGB color pixels, which range from 0 to 255. When the user clicks the camera on a specified weed, the program will compute the RGB pixel values.

Development of Graphical User Interface (GUI)

In this project, Microsoft Visual Basic 6.0 was used to develop the

Fig. 3 Flow chart of the software for automated weedicide sprayer

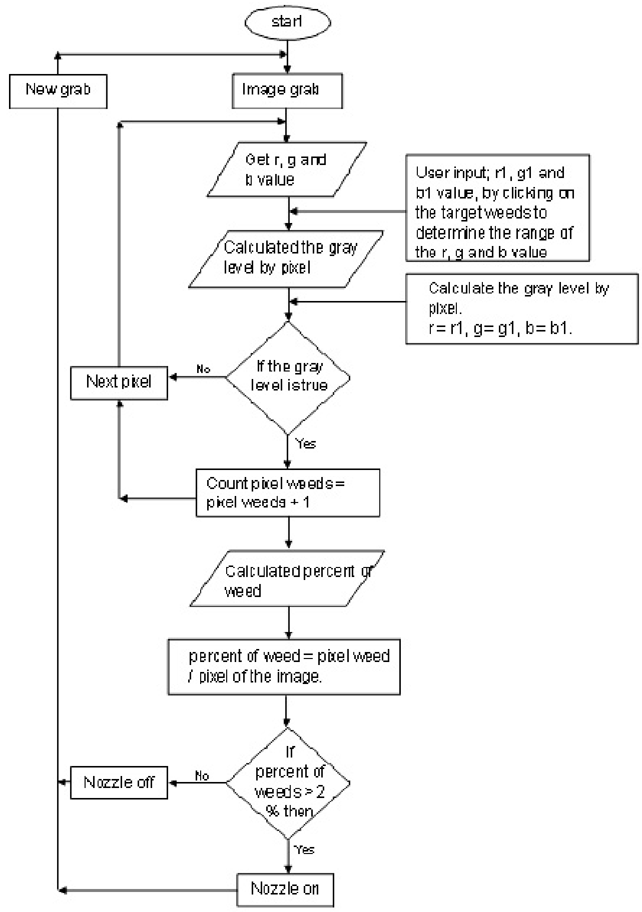


Fig. 2 Sample images captured and analyzed

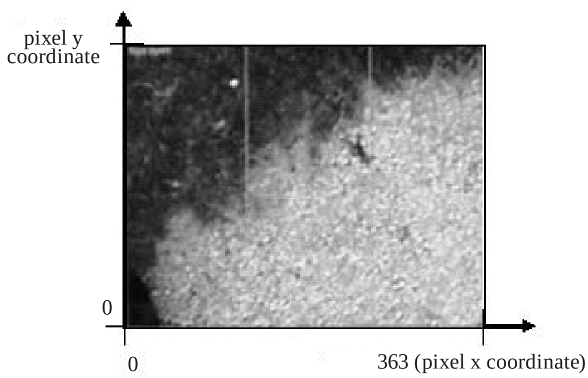
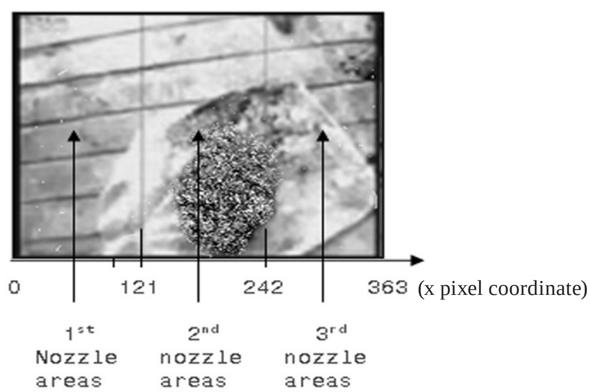


Fig. 4 Weeds captured with three frame for three nozzles



graphical user interface (GUI) to monitor the parameters that control the autonomous sprayer operations. **Fig. 3** shows the flow chart of the software showing the algorithm for the automated weedicide sprayer spraying system. The algorithm started with the camera capturing the image, analysing the image, calculating the percentage of RGB and instructing the nozzles to open or close for the spraying operations. **Fig. 4** shows the GUI screen of the monitor being divided into three frames captured by one camera. The three frames were for three units of spray nozzles. The camera captured the image and analyzed the red, green, blue (RGB) value in terms of computer pixels. The sprayer nozzle will turn on or off depending on the percentage or intensity of green color value of weeds.

During the start of the spraying operation, the web camera initially captured the image of weeds and analyzed the red, green, blue (RGB) value in terms of computer pixel. Through appropriate real-time image processing algorithm, which was based on color image as raw data, information of weeds locations and their densities were extracted. The image was sampled into a rectangular array of pixels. Each pixel had an x and y coordinate that corresponded to its location within the images. The green weed color was selected as a reference point and was set at the range of plus and minus 10 from the RGB selected pixel values. The program, as shown in **Fig. 5**, showed that the range of plus and minus 10 values was set from the RGB selected pixel value. These values were used as the reference to compare with the values of the RGB of weeds captured real-time during the spraying operation. The information of the reference point was sent to a sprayer controller.

Fig. 5 Percentage of green grass selection

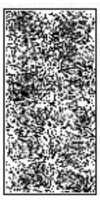
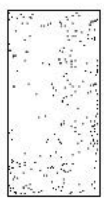
Area size	X 121	X 121	X 121	X 121	X 121	X 121
Pixel view						
Grass area	100%	75%	50%	25%	50%	0%
Pixel percent of green grass	20%	15%	10%	5%	10%	1%
Nozzle status	On	On	On	On	On	Off
Pump status	On	On	On	On	On	On
Sprayer status result	On	On	On	On	On	Off

Table 2 The status of nozzle based on percentage of rgb and pixel value of weeds

	Sprayer status	
Grass area	0% - 20%	20% - 100%
Pixel percent of green grass	0.00% - 4.0%	4.0% - 100%
Nozzle status	Off	On
Pump status	On	On
Sprayer status result	Of Spray	On Spraying

Results and Discussions

When the camera captures the real time image of weeds, the computer will calculate the percentage of green pixels available in the frame and compare with the RGB pixel of the reference point. When the green color of the weeds matched with the reference RGB value stored in the computer, it will trigger the nozzle to spray out the chemical solution to the target area. The normally closed (NC) solenoid valve at the nozzles will turn on when the camera detects the weed and turn off when the camera detects no weed. This on/off function will reduce the amount volume to be sprayed and therefore help to reduce hazardous to the environment as well as production cost. The normally open (NO) solenoid valve was installed at the chemical tank. If there was nothing to be sprayed, the NO solenoid valve will by pass the chemical liquid back to the tank. This was to avoid the high-pressure build up in the main sprayer line. There is a practical need for a real-time machine for weed detection and to reduce the use of agricultural chemicals. In the real-time system, response time is a critical parameter. Therefore, the overall system must be well visualized and designed for successful integration.

Table 2 shows the percentage of green grass that was set to open and close the nozzles and pump of the tank. The sprayer pump and the nozzles will be on at 20 to 100 % intensity of weeds and 4 to 100 % of pixels of green weeds. The pump and nozzles will open or close based on the percentage or intensity of green color pixel value of weeds. **Fig. 5** shows the six frames of green weeds captured by the two web cameras that were installed on the ATV. The figure shows the percentage of the area covered with the green grass and its percentage of pixel calculated by the program. The status of spraying shows that the nozzle only opens at the pixel of more than 20 %.

The concept of the smart sprayer, which includes PC web camera, personal computer, a programmable microcontroller ICPCON and sprayer system was achieved. The objective for this project was successful in detecting the presence of weeds and also the intensity of weeds by using camera vision. The normally closed (NC) solenoid valve was mounted at the nozzles for the purpose of ON/OFF of the nozzles. It will be 'ON' when the camera detects the weed and turn off when the camera detects no weed. This ON/OFF function will reduce the amount volume to be sprayed and therefore help to reduce hazardous to the environment as well as production cost.

Conclusions

The automated sprayer system was successfully developed using the combination of the electromechanical system, controllers, and the software. The automatic sprayer was tested in the real outdoor environment. In the real oil palm plantation environment, the variations of the daylight affect the image analysis of the weeds. To reduce the variations of light intensity of the outdoor environment, the RGB color values of the weeds were captured in real time. During the spraying operation, the on-line cameras captured the image of the weeds and compared with the reference color of weeds that was captured on real-time basis. Camera vision for the application of weedicide spraying was able to detect the presence of weeds and also the intensity of weeds.

The sprayer will spray the weedicide chemicals automatically based on the green color that has been recognized from image. The weeds captured by the camera in each frame were analyzed to activate the respective nozzle either to open or closed depending on the percentage or intensity of green colour value of weeds. The user-friendly graphical user interface (GUI) was easy to understand so that everyone could operate the autonomous sprayer. Weed detection at the time of spraying could be very valuable for reducing chemicals costs and reducing environmental contamination. Thus, the introduction of this automatic sprayer for the Malaysian farmers is very timely and has great impact for commercialization.

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Tractor Front-Mounted Cross-Conveyor Paddy Straw Thrower

by

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Abstract

Paddy straw management in combine harvested fields is a major problem encountered under the paddy-wheat cropping system. The loose straw left behind in the combine harvested field leads to frequent choking of the furrow openers of the no-till drill. A functional prototype of tractor front-mounted cross-conveyor straw thrower was developed to ensure the smooth working of the no-till drill while sowing the wheat crop. The prototype comprised a pick-up reel, cross-conveyor and straw distributor. The straw thrower was evaluated in the field to optimize key parameters like reel speed index (3.4, 4.2 and 5.2) and conveyor speed index (4.3, 5.5 and 6.5). The belt width of the designed cross-conveyor was 60 cm and cleat row spacing of cross conveyor was 37.5 cm. The average pickup efficiency (84.18 %) of the functional prototype of the straw thrower was the highest at reel speed index of 4.2 in field experiments. The pickup efficiency was also the highest at conveyor speed index of 4.3. The average straw management efficiency (92.38 %) of the functional prototype of the straw thrower was also the highest at reel speed index of 4.2. The uniformity of paddy straw displaced was the highest at conveyor speed index of 4.3 in comparison with conveyor speed indices of 5.5 and 6.5 during field tests of the functional prototype. Moisture content of the standing stubbles was reduced during four weeks from 76.4 to 54.2 % and for loose straw it was reduced from 41.5 to 11.5 %. Field performance of the experimental machine set at the optimal combination of independent parameters was comparable with the performance of the no-till drill operated in a straw-free field. Effect of the mulch created by the straw thrower on the crop establishment and soil parameters was also studied. The seed germination by sowing wheat with the experimental machine was not significantly different from the germination of crop sown by the no-till drill in straw-free fields. The difference between the maximum and minimum temperature of soil at 5 cm depth was lower (narrow range) in the mulched field (2.77 ºC) than the straw-free field (7.73 ºC). The soil temperature variation between the maximum and minimum was narrowed down by the mulch created by the straw thrower.

Introduction

Rice-wheat cropping system is one of the most extensively used cropping systems in Indo-Gangetic planes of India. In Punjab State, combines are extensively used to harvest rice and wheat crops. Use of rice straw for cattle feed or other purposes is not very popular in the Punjab and adjoining areas. Management of paddy straw left behind in the combine harvested paddy field is, thus, a major problem of the rice-wheat cropping system. Farmers usually burn it, which leads to environmental pollution and loss of precious soil nutrients. The no-till technology with residue retention is a major step for enhancing sustainability of the rice-wheat cropping system. The standing stubbles in the combine harvested paddy field do not affect the performance of no-till drill significantly. However, the loose straw left behind in the combine harvested fields in the windrows results in frequent choking of the furrow openers of the drill. Therefore, a functional prototype of a new machine, i.e. tractor operated cross-conveyor straw thrower, was developed for sowing of wheat crop with no-till drill directly in combine harvested paddy fields having standing stubbles and loose straw.

Review of Literature

Sacinykh *et al.* (1999) reported an investigation of the working tools of machines designed to cut straw from windrows. The studies were carried out at the Research Institute of Agriculture of North-East in co-operation with Marijsky Research Institute of Agriculture, Kirov, Russia. The most significant factors influencing straw cutting and distribution were rotor and feeding conveyer speed and the angle of the directing deflectors. The most even cut and straw distribution occurred when the rotors revolved in the opposite direction. The hammer-type (impact) working tools cut the straw with an even distribution.

Siemens *et al.* (2000) developed a residue management strategy to improve performance of hoe-type no-till drill. Acceptable no-till drill performance in terms of stand count, plant growth and yield potential was investigated when standing stubbles were less than 20 cm height and the residues were uniformly distributed. Uniform distribution of the residues was the most important factor for maximizing the direct seed drill performance in heavy residues. Drill attachments such as coulter and a residue management wheel yielded mixed and improved results, respectively. As expected, when nearly all residues were removed, drill performance was found to be excellent. Chopping the residues into 3.2 cm long pieces provided stand counts and seedling yield potential parameters equivalent to those of removing the residues completely. It is not known whether cost of the energy required for this operation was economically viable but it did provide a hope for an improved residue management strategy over what was currently available.

Gupta and Rickman (2002) suggested certain design improvements in existing zero-till machines for planting under residue conditions. They reported and confirmed that no-tillage with residue retention was a major step forward in the right direction for enhancing sustainability of the rice–wheat cropping system. They inferred that present zero-till machines in India raked the loose residues. They suggested that when designing a zero-till machine, it must be able sow crops in the presence of crop residues with minimum soil disturbance in different soil types and the drill frame should be of sufficient strength and adaptability to hold various attachments.

According to siemens *et al.* (2004), direct drilling helped in timely sowing of wheat, after paddy, in paddy-wheat cropping systems. It reduced the cost of production, controlled soil erosion and weeds, conserved soil moisture, increased water infiltration rate and also maintained or increased the quantity of organic matter in the soil. Despite these advantages, the percentage of no-till farmland in the Pacific Northwest (PNW) was only 7.5 % and lagged behind the national (USA) average of nearly 20 %. Limited adoption of this practice in the PNW was not only due to economic and agronomic concerns (Young and Upadhyaya (2003), Veseth and Wysocki (2003), but also due to lack of trouble free, reliable seeding equipment for planting in the high density residue ranging from 3 t/ha to 10 t/ha, encountered in the region (Lindwall and Anderson 1977; Erbach *et al*., 1983; Hyde *et al.,* 1987; Wilkins *et al*., 1992).

Material and Methods

A functional prototype of tractor front-mounted cross-conveyor straw thrower was developed and fabricated. Field experiments on sowing performance and crop establishment parameters in the presence of paddy straw were conducted. The salient details of the materials and methods used in this study are discussed in the paragraphs that follow.

Field Evaluation of Straw Thrower

Field evaluation of the experimental machine was conducted at the University Seed Farm, Ladhowal (Ludhiana). The paddy crop was harvested by a combine harvester and tractor front-mounted cross-conveyor straw thrower was used to pick, convey and shift the straw uniformly on one side of the machine (**Fig. 1**).

Fig. 1 Prototype of tractor front-mounted cross-conveyor straw thrower

Fig. 2 Straw thrower throwing paddy straw on canvas sheets (2 × 4 m)

Independent Parameters

Values of two independent parameters namely reel speed index (RI) and conveyor speed index (CI) were optimized for sowing the wheat crop in combine harvested paddy fields with zero tillage.

Reel speed index (RI): Reel speed index of the pickup unit of straw thrower was defined as:

Reel speed index (RI) =
[Peripheral speed of tip of pickup finger, m/s] / [Forward speed of machine, m/s]

Reel speed index could be changed either by changing the RPM of reel driving pulley or by changing the forward speed of travel. In the experiments, different reel speed indices were obtained by changing diameter of pulley on pickup reel shaft. Forward speed of the machine was kept constant at 3.2 km/h. Three levels of reel speed index namely 3.4, 4.2 and 5.2 were selected and obtained achieved by using three pulleys of diameter 200, 150 and 125 mm, respectively, on the pickup reel shaft and constant forward speed of circular bin.

Conveyor speed index (CI): Conveyor speed index of the cross-conveyor was defined as :

Conveyor speed index (CI) =
[Linear speed of belt conveyor, m/s] / [Forward speed of machine, m/s]

The three levels of conveyor speed index namely 4.3, 5.5 and 6.5 were selected and achieved by using three pulleys of 225, 175 and 150 mm diameter, respectively, on conveyor shaft and 150 mm diameter pulley on an electric motor shaft in laboratory experiments.

Fig. 3 Loose paddy straw thrown and distributed on canvas sheets

Forward speed of the tractor was kept at 3.2 km/h by driving the tractor in third low gear with 1400 RPM engine speed. The three levels of reel speed index (RI) were obtained in field experiments by using 100, 125 and 162.5 mm diameter pulleys on the output shaft of the gear box and 250 mm diameter pulley on the pickup reel shaft of the functional prototype of the tractor front-mounted cross-conveyor straw thrower. The three levels of conveyor speed index (CI) were obtained in field experiments on the functional prototype of straw thrower by using pulley pairs of diameter 300-175, 325-150 and 325-125 mm on the intermediate and conveyor shaft, respectively. The cleat row spacing (S) was 37.5 cm and belt width (B) was 60 cm to convey the bunches of paddy of 50-60 cm length in field experiments.

Dependent Parameters

The dependent parameters of straw thrower performance were selected for field experiments which represented its performance from straw pickup, management and uniformity of distribution point of view. These parameters were measured/determined and used for optimization of independent parameters.

Straw pickup and management efficiency: Straw pick up efficiency was defined as:

Straw pickup efficiency (η_p) *% = [Straw picked, g] / [Total straw available, g] × 100*

Straw management efficiency (η_m) *% = [Straw picked, g + Straw passed, g] / [Total straw available, g] × 100*

Total straw available, g = (Conveyed, g + Passed, g + Accumulated, g)

Straw picked was the weight of straw (in grams) that was picked, conveyed and distributed on canvas sheets by the straw thrower. Straw passed was the weight of straw that was left on the surface after passing through the machine. Straw picked by the straw thrower was collected on two 4 × 2 m canvas sheets in each run of the experimental machine (**Fig. 2**) and weight of straw in one meter along machine run was taken for 4 m length. The weight of straw, which was left after passing through the machine was taken for 4 m field strip (**Fig. 3**) and divided equally for one meter grid along the run of machine. The percentage of straw picked and passed was calculated. The weight of standing stubbles was also taken to know the distribution of paddy straw.

Distance and uniformity of straw thrown: The distance of straw thrown (shifted) was the distance straw reached from the end of straw conveyor. The maximum distance of throw was known from the grid in which the farthest piece of straw or chaff was available. The uniformity of the straw thrown by the straw thrower was determined by calculating the coefficient of variance (CV) of the percentage of weight of straw collected in each strip of 50 cm from the end of conveyor.

Experimental Design and Field Layout

Field evaluation of the experimental machine was conducted by using split-plot experimental design. There were two independent parameters, i.e. reel speed index (RI) and conveyor speed index (CI), and each had three levels of 9 (3 × 3) treatment combinations for pickup and management efficiency and straw accumulation. Each treatment combination was replicated thrice to make total number of experiment units 27 (9 × 3). Evaluation for uniformity of straw thrown by the experimental machine was conducted by using RBD. There were three treatments, i.e. levels of conveyor speed index (CI), and each treatment combination had twelve replications to make total number of experiment units 36 (12 × 3). The total field area of 1222 m^2 (27 × 30 × 1.5) was divided into 3 blocks. Each block had an area of 407.3 m^2 (9 × 30 × 1.5), in which 3 replications were allocated. Each block was divided into 3 main plots in which 3 levels of reel speed index RI1, RI2 and RI3 were randomized. Each of these main plots was split into 3 sub-plots to assign 3 levels of conveyor speed index CI1, CI2 and CI3 at random.

Measurement of Moisture Content of Paddy Straw

The moisture content of standing stubbles and loose paddy straw was measured at an interval of one week on wet weight basis (wwb) in the research lab at the Departmental Farm. The straw samples were dried at 60 ºC for 72 hours as per ASAE standard S358.2 DEC93.

Plant Emergence

Plant emergence was also an indicator of the sowing performance of the machine under residue conditions. The plant emergence was also affected by soil moisture, seed-soil contact and seed coverage; all affected by residue. The plant emergence count was taken as number of plants emerged per unit length from 9 to 21 days after sowing (DAS), up to constant emergence. The number of seedlings per meter length was taken from 8 spots in each plot and the mean values were determined as representative plant stand for both the treatments.

Soil Temperature

Soil temperature was recorded daily for all the plots for 23 days after sowing. Mercury type long thermometers were installed in the field to record the minimum and maximum temperatures during a 24 hour period in both treatments. Three thermometers were installed in each plot. Minimum and maximum temperatures were recorded at 7:30 A.M. and 2:30 P.M. in the experimental plots.

Results and Discussion

The results of field experiments of functional prototype of straw thrower are discussed in the following sub-sections.

Effect of Reel Speed Index on Straw Pickup and Management Efficiency

Straw thrower managed the straw in two ways; first the straw was picked, conveyed and thrown by the straw thrower to one side of the

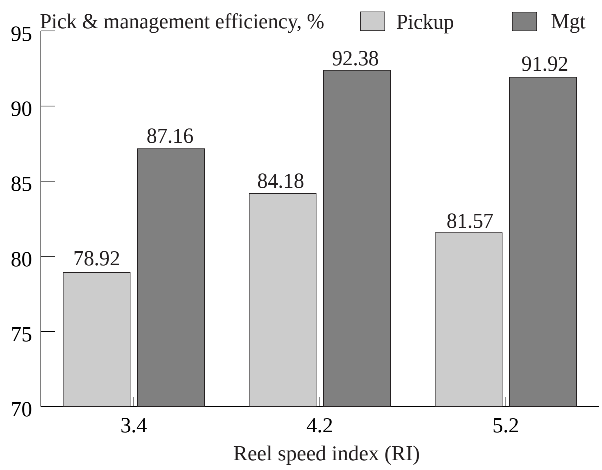
Table 1 Effect of reel speed index on straw pickup efficiency at Ladhowal Farm

Reel speed index (RI)	Conveyor speed index (CI)	Pickup efficiency (η_p), %				
		R1	R2	R3	Avg,	
3.4	4.3	80.91	81.82	80.69	81.14	
	5.3	82.13	82.83	74.62	79.86	78.92
	6.5	78.22	75.53	73.58	75.78	
4.2	4.3	82.30	83.62	86.83	84.25	
	5.5	86.38	85.09	83.98	85.15	84.18
	6.5	84.06	83.91	81.49	83.15	
5.2	4.3	85.94	85.07	82.25	84.42	
	5.5	81.11	76.94	82.53	80.19	81.57
	6.5	76.53	82.83	80.93	80.10	
	F-ratio = 10.57				CD = 3.18	

Table 2 Effect of reel speed index on straw management efficiency at Ladhowal Farm

Reel speed index (RI)	Conveyor speed index (CI)	Pickup efficiency (η_p), %				
		R1	R2	R3	Avg,	
3.4	4.3	86.58	90.95	90.37	89.30	
	5.5	88.21	88.67	82.66	86.51	87.16
	6.5	86.48	85.42	85.10	85.67	
4.2	4.3	90.90	91.62	93.90	92.14	
	5.5	94.58	92.81	93.80	93.73	92.38
	6.5	90.38	92.14	91.27	91.26	
5.2	4.3	94.21	92.63	90.36	92.40	
	5.5	91.54	88.34	93.30	91.06	91.92
	6.5	89.54	95.43	91.91	92.29	
	F-ratio = 38.87				CD = 1.82	

Fig. 4 Effect of reel speed index (RI) on straw pickup and management efficiency



machine and secondly the straw left passed through the openers of no-till drill. The data on effect of different levels of reel speed index on straw pickup (η_p) and management efficiency (η_m) are given in **Tables 1** and **2** and depicted in **Fig. 4**. The average pickup (78.92 %) and management (87.16 %) efficiency at reel speed index of 3.4 was significantly lower than the average pickup (84.18 %) and management (92.38 %) efficiency at reel speed index of 4.2 (Appendix C.9). There was no significant difference in pickup and management efficiency between 4.2 and 5.2 reel speed indices but pickup efficiency (84.18 %) and management (92.38 %) efficiency were higher at reel speed index of 4.2 as compared with 5.2. Therefore, the reel speed index of 4.2 was found to be the best for picking the paddy straw in situ. Similar results were obtained in the laboratory experiments with the same levels of reel speed index but the value of pickup efficiency was slightly higher in laboratory experiments than in field experiments.

Effect of Conveyor Speed Index on Straw Pickup and Management Efficiency

The data for effect of different levels of conveyor speed index on straw pickup (η_p) and management efficiency (η_m) are given in **Table 3** and depicted in **Fig. 5**. The effect of conveyor speed index was significant on straw pickup efficiency. The average pickup efficiency (83.27 %) at conveyor speed index of 4.3 was significantly higher than the pickup efficiency (79.67 %) at conveyor speed index of 6.5. The pickup efficiency (81.73 %) at conveyor speed index of 5.5 was also higher than the conveyor speed index of 6.5 but the difference was non-significant. The pickup efficiency was also higher at conveyor speed index of 4.3 than at conveyor speed index of 5.5 in lab experiments. This was possibly due to higher speed of belt conveyor resulting in higher destabilization forces for straw, which affected the pickup and management efficiency. The effect of conveyor speed index on straw management efficiency was non-significant.

Effect of Conveyor Speed Index on Uniformity of Straw Thrown: The cross-conveyor and straw distributor were treated as one unit and the speed ratio (1.5) between distributor and conveyor was fixed in lab and field experiments. The data of effect of conveyor speed index on uniformity of straw thrown is presented in **Table 4**. The effect of conveyor speed index (CI) on uniformity of straw thrown was significant with F-ratio of 20.67. The critical difference (CD) of 3.55 indicated that uniformity (20.92 % CV) at conveyor speed index

Table 3 Effect of conveyor speed index on straw pickup efficiency at ladhowal farm

Conveyor speed index (CI)	Reel speed index (RI)	Pickup efficiency (η_p), %				
		R1	R2	R3	Avg,	
4.3	3.4	80.91	81.82	80.69	81.14	83.27
	4.2	82.83	83.62	86.83	84.25	
	5.2	85.94	85.07	82.25	84.42	
5.5	3.4	82.13	82.83	74.62	79.86	81.73
	4.2	86.38	85.09	83.98	85.15	
	5.2	81.11	76.94	82.53	80.19	
6.5	3.4	78.22	75.53	73.58	75.78	79.68
	4.2	84.06	83.91	81.49	83.15	
	5.2	76.53	82.83	80.93	80.10	
	F-ratio = 4.18				CD = 2.72	

Fig. 5 Effect of conveyor speed index (CI) on straw pickup and management efficiency

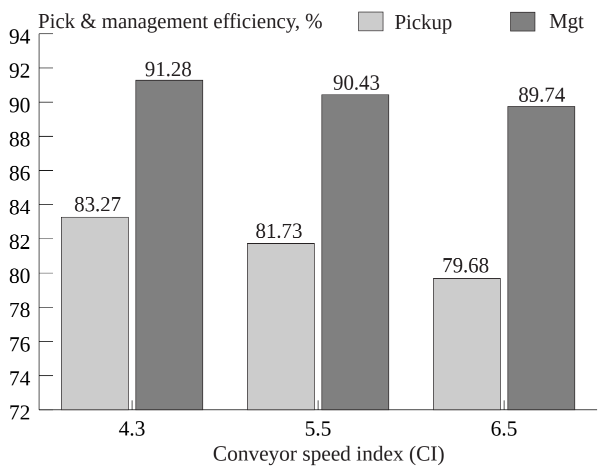


Table 4 Uniformity of straw thrown in field experiment at ladhowal farm

Uniformity of straw thrown, CV%		
CI1 = 4.3	CI2 = 5.5	CI3 = 6.5
20	28	30
20	27	31
23	29	35
20	25	31
19	25	36
12	18	28
24	31	35
22	27	29
25	27	33
17	32	35
17	31	37
32	32	22
20.92	27.67	31.83
F-ratio = 20.67		CD = 3.55

(CI1) of 4.3 was significantly higher from the other two conveyor speed indices (CV of 27.67 and 31.83 %), i.e. 5.5 and 6.5. Uniformity was maximum for the range of experiments conducted with minimum CV (20.92 %) at conveyor speed indices of 4.3. Moreover the lowest speed also contributed to less wear and tear, vibrations and energy for the cross-conveyor. Similar results were obtained in the laboratory experiments.

Optimization of Independent Parameters of Cross-Conveyor Straw Thrower

The results of the different dependent parameters studied (straw pickup and management efficiency (%), straw accumulation (kg/ha), uniformity of straw thrown (CV basis) of the experimental machine as affected by independent parameters, i.e. reel speed index and conveyor speed index) are summarized in **Table 5**. The reel speed index of 4.2 was significantly better from the other two levels of 3.4 and 5.2 in terms of pickup efficiency (84.18 %), straw management efficiency (92.38 %) and straw accumulation (299 kg/ha). This reel speed index of 4.2 was also found to be the best in laboratory experiments. Therefore, the reel speed index of 4.2 was used for sowing of wheat crop in field experiments.

The first level of conveyor speed index of 4.3 was found to be better in terms of uniformity of straw thrown with CV of 20.92 %, which was significantly lower with CV values of 27.67 and 31.83 % for the other two conveyor speed indices. The pickup efficiency (83.27 %) was, also, found highest at this conveyor speed indexes. The conveyor speed index of 4.3 was found to be the best in laboratory experiments. The lowest value of conveyor speed index contributed to less wear and tear, vibrations and energy requirements. Hence, this value (4.3) of conveyor speed index was used for sowing of wheat crop by the machine. The cleat row spacing (S2) of 37.5 cm was already optimized in lab experiments. This value (37.5 cm) was also used for the functional prototype of straw thrower in field experiments. The belt width (B) of the cross-conveyor was determined as 60 cm by analytical method for 1.5 m wide pickup unit of prototype straw thrower, which was used in field experiments for sowing of wheat crop.

Moisture Content of Paddy Straw

The moisture content of standing stubbles and loose paddy straw was measured at an interval of one week on wet weight basis (wwb). The moisture content of standing stubbles decreased from 76.4 to 54.2 % on wwb and for loose straw moisture content decreased from 41.5 to 11.5 %. The paddy straw moisture content is an important factor as it affects the machine performance.

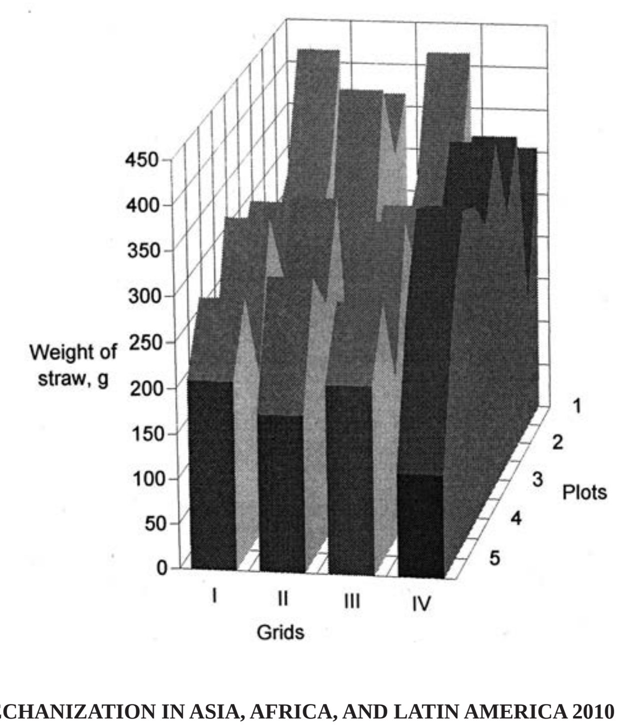
Straw Conveying and Distribution during Sowing Operation

The weight of paddy straw thrown in a 1 × 1 m^2 grid by the tractor front-mounted cross-conveyor straw

Table 5 Optimum parameters of straw thrower in field experiments

Independent parameters	Pickup efficiency, %			F-ratio	CD
Reel speed index (RI)	3.4	**4.2.**	5.2	10.57	3.18
	78.92	**84.18**	81.57		
Conveyor speed index (CI)	**4.3**	5.5	6.5	4.18	2.72
	83.27	81.73	79.68		
	Management eff8c8ency, %				
Reel speed index (RI)	3.4	**4.2**	5.2	38.87	1.82
	87.16	**92.38**	91.92		
	Straw accumulation, kg/ha				
Reel speed index (RI)	3.4	**4.2**	5.2	30.62	88.49
	526	**299**	323		
	Uniformity of straw thrown, CV %				
Conveyor speed index (CI)	**4.3**	5.5	6.5	20.67	3.55
	20.92	27.67	31.83		

Fig. 6 Weight of paddy straw thrown by straw thrower during sowing of wheat



thrower while sowing wheat with no-till drill was measured on 4 × 2 m sheets. The loose paddy straw thrown by the machine was collected and weighed from a square meter area. Observations of 40 grids, 8 each (one sheet) from 5 plots, where straw thrower with no-till drill was used are given in Table 6 and depicted in **Fig. 6**. The weight of straw thrown in grids varied from 105 to 415 grams with an average of 274.75 g. The coefficient of variation (CV) was 29.21 %, which was slightly higher than the value of CV observed at the Ladhowal farm (without sowing) experiments.

Germination Count

The mean values of plant emergence, i.e. number of plants per meter row length, are shown in **Fig. 7**. After 9 days of sowing, 14.4 plants had emerged in the mulched field as compared to 13.03 plants in the field without mulch. Average number of plants emerged per meter row length in 21 DAS were 26.1 and 27.03 in the field having mulch created by straw thrower and in control, respectively. Analysis of variance for the effect of mulching on the number of plants emerged showed that mulch had no significant effect on the plants emergence. **Fig. 8** also shows that plant emergence rate was almost the same for both the treatments. A view of germination of wheat crop in mulch conditions is shown in **Fig. 8**.

Variation in Soil Temperature

The average maximum and minimum temperature of soil and ambient temperature of the farm were recorded and are plotted in the **Fig. 9**. Maximum temperature of soil was lower (varied from 16.38-19.00 ºC) for mulched (straw thrower) field as compared to the temperature of the soil (varied from 20-23.77 ºC) for control, i.e. unmulched field. Minimum temperature of the soil was more (varied from 13.08-16.69 ºC) for mulched field as compared to the temperature of the soil (varied from 12.31-16.46 ºC) for control. **Fig. 9** shows that mulching with paddy residue had reduced the maximum temperature of the soil and slightly increased the minimum temperatures of the soil in the germination period of the crop. The difference between maximum and minimum temperatures (1 to 4 ºC, average 2.77 ºC) had been reduced and the range of temperature variation had narrowed by the mulch of paddy straw as compared to bare field

Table 6 Distribution of weight (g) of paddy straw in grids (m²) thrown by straw throwerduring sowing of wheat

Grids (1 × 1 m²)			
I	II	III	IV
280	365	415	305
230	310	285	140
275	405	240	355
175	215	195	285
210	285	310	285
255	105	245	310
350	355	330	350
285	255	175	365
410	305	280	270
180	175	210	115
Total = 10,990	Mean = 274.75	SD = 80.26	CV = 29.21%

Fig. 7 Germination of wheat in clean and straw thrown the field

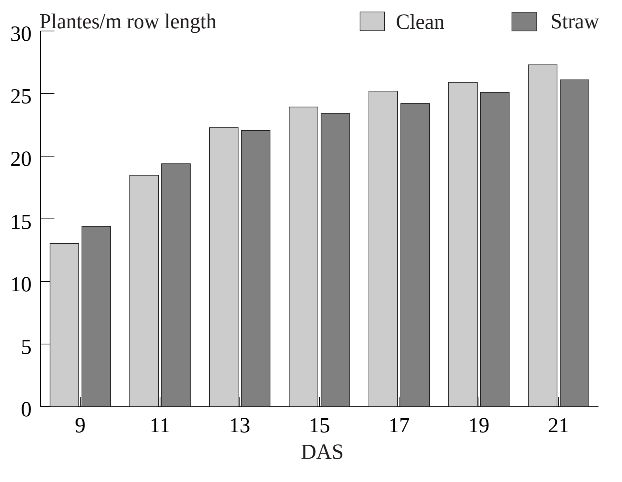
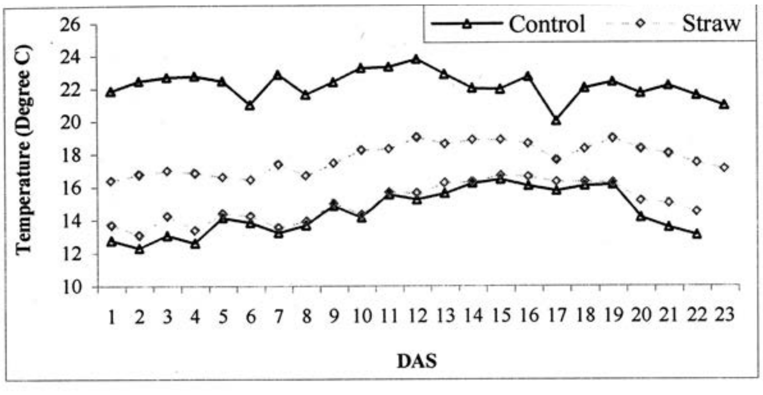


Fig. 8 Germination of wheat (21 DAS) in presence of paddy straw

Fig. 9 Minimum and maximum temperature of soil in field experiment



where the difference was from 3.92 to 10.38 ºC with an average of 7.73 ºC. This decrease in the maximum temperature of soil taken in the afternoon and increase in minimum temperature taken in the morning could be attributed to the fact that mulch acted as an insulating material on the soil surface, reducing the amount of heat transfer from atmosphere to soil and vice-versa.

Conclusions

The belt width of the designed cross conveyor was 60 cm and cleat row spacing of cross conveyor was 37.5 cm. The average pickup efficiency (84.18 %) of the functional prototype of the straw thrower was the highest at reel speed index of 4.2 in field experiments. The pickup efficiency was also the highest at conveyor speed index of 4.3. The average straw management efficiency (92.38 %) of functional prototype of the straw thrower was also the highest at reel speed index of 4.2. The uniformity of paddy straw displaced was the highest at conveyor speed index of 4.3 in comparison with conveyor speed indices of 5.5 and 6.5 during field tests of the straw thrower. Moisture content of the standing stubbles was reduced during four weeks from 76.4 to 54.2 % and for loose straw from 41.5 to 11.5 %. Field performance of the experimental machine set at the optimal combination of independent parameters was comparable with the performance of the no-till drill operated in a straw-free field. Effect of the mulch created by the straw thrower on the crop establishment and soil parameters was also studied. The seed germination by sowing wheat with the experimental machine was not significantly different from the germination of crop sown by the no-till drill in straw-free fields. The difference between the maximum and minimum temperature of soil at 5 cm depth was lower (narrow range) in mulched field (2.77 ºC) than the straw-free field (7.73 ºC). The soil temperature variation between the maximum and minimum was narrowed by the mulch created by the straw thrower. Based on the foregoing results, it was concluded that the tractor front-mounted straw thrower was quite a useful machine for sowing of wheat in combine harvested paddy fields.

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Modernization of Indian Roller Gins and the Effect on Cotton Fibre Quality

by

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Abstract

Technology Mission on Cotton (TMC) was launched for modernization/setting up of new ginning and pressing factories equipped with better machinery and civil infrastructure to process cotton into low trash/contamination-free cotton. However, in the process of removing the foreign matter from the cotton, by way of modernization, the concern about the mechanical damage to the fibres arose by the ginners. Hence, to answer the concern raised by the ginners, a detailed scientific study was conducted to find the effect of modernization in roller gins on fibre quality. Experimental trials were conducted in TMC approved commercial a modernized gin on Ankur-651 and MCU-5 variety. Modernization in roller gins did not significantly affect the HVI fibre quality parameters such as 2.5 % span length, uniformity ratio, fineness, strength and elongation. However, a marginal decrease in 2.5 % span length and strength was observed, which was within the acceptable range of testing. The results showed that machinery such as pre-cleaner, double roller gin and lint cleaner does not have any adverse effect on the HVI fibre quality parameters. Also the pneumatic conveying systems for seed cotton and lint at different stages did not affect the HVI fibre quality parameters. The effect of modernization on AFIS fibre quality parameters a marginal increase in short fibre content, immature fibre content and fibre neps. The visible foreign mater and seed coat neps decreased with the modernization in gins. Overall, the study indicated no significant reduction in fibre quality parameters as tested by HVI and AFIS for the gins modernized as per the TMC guidelines. The results of the study favor the modernization of gins apart from other advantages of modernization.

Introduction

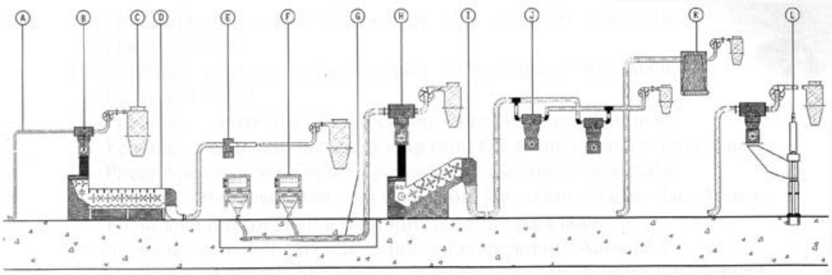
The ginning industry is a primary cotton processing industry that operates seasonally for six to eight months in a year. The major function of a gin is to separate the seed the seed and the lint cotton, and form a bale of lint. India has over 4,000 gins which are dispersed all over the nine cotton-growing states. In India about 70 % of cotton is being ginned on double roller (DR) gins. In conventional gins, either ginning or pressing or both operations are performed but the entire handling of seed cotton, lint, cottonseed and bales is done manually and the machines used are old and outdated, resulting in lint quality degradation. In modernized or automatic gins all the unit operations are done automatically except unloading of cotton, preparation of heap, feeding to suction system and handling of bales. In modernized gins, cotton moves from one processing stage to another throughout the entire ginning plant through conveying systems and processing machines. The pre-cleaning, ginning, lint cleaning and baling are the imporrtant processes, which the cotton undergoes in a modernized gin.

In a modernized gin, the seed cotton passes through the pneumatic conveying systems, stone catcher, pre-cleaner, automatic feeding system and then gets ginned on double roller gins. Cylinder type pre cleaners are employed before ginning for removing foreign matter such as heavy impurities and immature bolls from seed cotton. It also performs a most critical function of opening the cotton and removing fine trash. The distribution of seed cotton to individual DR gins is achieved pneumatically, mechanically or pneumatic as well as by electromechanical means. Ginning (separation of fibres from the seed) is carried out by double roller gins. The lint obtained after ginning is conveyed pneumatically to the lint cleaner and, then, pneumatically to the pala house. A spade type cylinder lint cleaner removes leaf particles, motes, broken seeds, fibre entanglements grass and bark that remain in cotton after seed cotton cleaning and ginning. Moisturization of the lint to optimium moisture content is carried out in the pala house. Moisturization is also done during ginning and pressing operations to mintain a moisture content of about 8 %. The conditioned lint is conveyed pneumatically to the press house for final bale pressing. The seed is conveyed from the gin house to a seed platform by bucket elevator and screw conveyor. Also, to prevent contamination, the cotton is stored on a raised platforms. Modernization of machinery is also supported by improved civil infrastructure.

With the globalization of trade under WTO, enormous opportunities await Indian textiles particularly in the overseas markets. In anticipation, the Government of India launched the Technology Mission on Cotton (TMC) to strengthen the raw material base for Indian textile industry through a series of measures by which contamination-free cotton with good fibre attributes would be made available to spinning mills. One of the measures under TMC has been the modernization/setting up of new ginning and pressing (G&P) factories equipped with better machines and civil infrastructure to process cotton into low trash/contamination-free cotton. Financial assistance has been offered to gins through Mini Mission IV of TMC after completion of the project, in accordance with norms specified with respect to machinery and civil infrastructure. It was hoped that by the end of the tenth plan, about 1000 gins would be modernized and the majority of the cotton produced in the country would be processed in modernized G&P factories and would conform to the world standards in quality.

Modernization of G&P factories succeeded in bringing the trash level down to about 1 % in the processed bale. However, in the process of removing the foreign matter from the cotton, the ginners and the traders were concerned about the mechanical damage to the fibres, especially the reduction in fibre quality related to staple length, short fibre content and neps. Due to increase in quality concerns many ginners in India have not been able to decide in favour of modernization. Many queries have been received by the Central Institute for Research on Cotton Technology (CIRCOT) to determine how modernization has been beneficial to them in terms of improvement in quality of cotton. Hence, to remove the fears in the minds of reluctant ginners and to urge them to join the TMC bandwagon, a detailed scientific study was carried out to determine the effect of modernization in roller gins on fibre quality.

Fig. 1 Schematic diagram depicting the sequence of machinery in used a modernized gin



A- Ducting line, **B**-Air separator, **C**-Cyclone with suction fan , **A, B& C** - Pneumatic seed cotton conveying system from platform to pre-cleaner, **D**- Pre-cleaner, **E**- Pneumatic seed cotton conveying system to distribute material to the DR gin, **F**- Double roller gins, **G &H**-Pneumatic lint conveying systems for collection of lint from the DR gins to a lint cleaner, **I**- Post cleaner, **J**- Pneumatic lint conveying system from lint cleaner to lint pala house, **K**- Pneumatic lint conveying system from lint

Materials and Methods

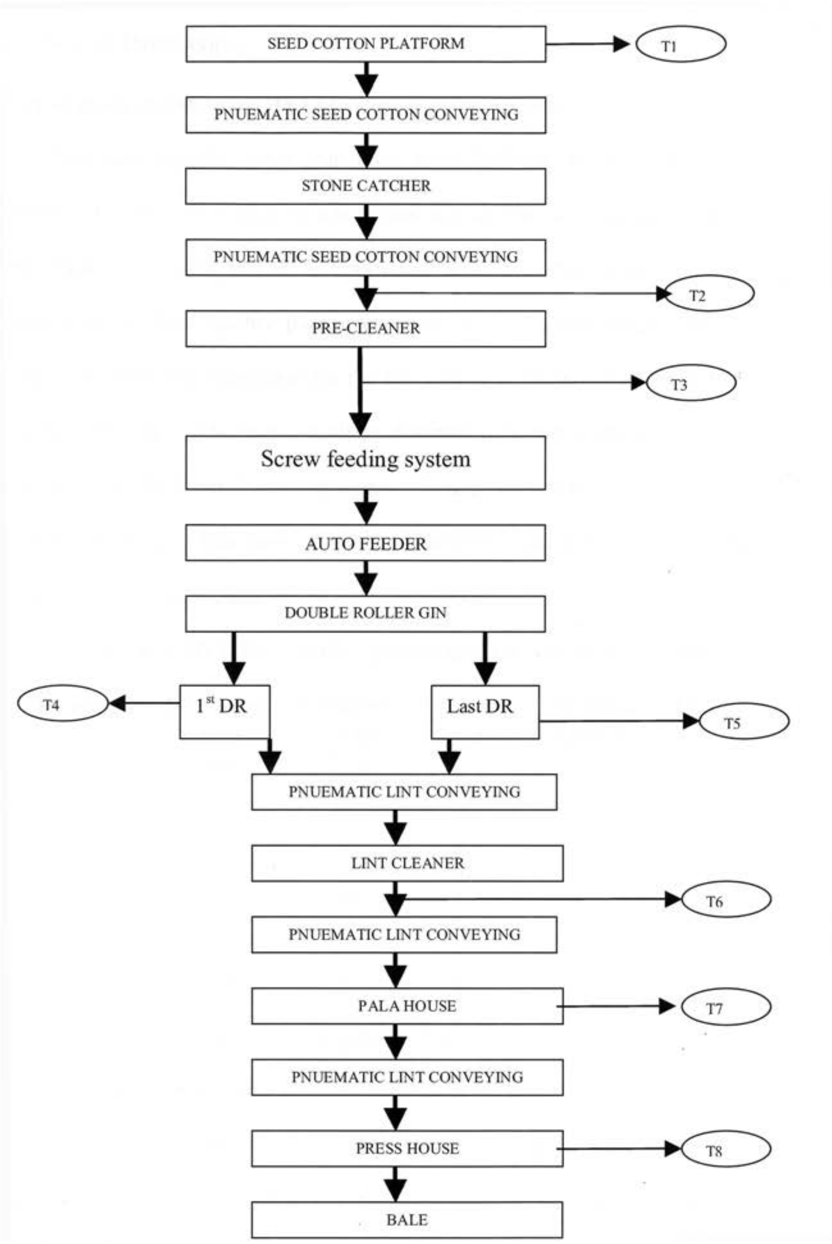
Experimental trials were carried out in a TMC approved modernized gin equipped with all the essential machinery and civil infrastructure. The sequence of machinery and automation systems used during the experimental trials is shown in **Fig. 1**.

A: Ducting line, B: Air separator, C: Cyclone with suction fan, A, B & C: Pneumatic seed cotton conveying system from platform to pre: cleaner, D: Pre: cleaner, E: Pneumatic seed cotton conveying system to distribute material to the DR gin, F: Double roller gins, G & H: Pneumatic lint conveying systems for collection of lint from the DR gins to a lint cleaner, I: Post cleaner, J: Pneumatic lint conveying system from lint cleaner to lint pala house, K: Pneumatic lint conveying system from lint pala house to press house, L: Bale press

Seed cotton of two varieties, Ankur-651 and MCU-5, was procured directly from the farmers to ensure the purity. Ten quintals of seed cotton for each variety was processed in a selected modernized commercial gin. The seed cotton and lint samples were collected at different stages of cotton processing; at the heap, before and after pre-cleaning, after automatic feeding, after ginning, before and after lint cleaning, pala house and press house. Ten samples were collected at each stage of processing and tested on HVI (High Volume Instrument) and AFIS (Advanced Fibre Information System). The fibre properties measured were 2.5 % span length, uniformity ratio, strength, fineness , short fibre content, fibre neps, seed coat neps and visual foreign matter. Flow diagrams depicting the stages at which the samples were drawn during cotton processing are shown in **Fig. 2**. The different stages at which the samples were drawn are identified as shown below:

T1: Heap
T2: Pneumatic conveying of seed cotton
T3: Pneumatic conveying of seed cotton + Pre:cleaning
T4: Pneumatic conveying of seed cotton + Pre:cleaning + Automatic Feeding, 1st DR
T5: Pneumatic conveying of seed cotton + Pre:cleaning + Automatic Feeding, last DR
T6: Pneumatic .conveying of seed cotton + Pre:cleaning + Automatic Feeding + Pneumatic lint conveying from DR to lint cleaner + lint cleaner
T7: Pneumatic conveying of seed cotton + Pre:cleaning + Automatic Feeding + Pneumatic lint conveying from DR to lint cleaner + lint cleaner + Pneumatic lint conveying from lint cleaner to pala house
T8: Pneumatic conveying of seed cotton + Pre-cleaning + Automatic Feeding + Pneumatic

Fig.2 Flow diagram depicting the stages at which the samples are drawn during cotton processing in modernized gins



lint conveying from DR to lint cleaner + lint cleaner + Pneumatic lint conveying from lint cleaner to pala house + Pneumatic lint conveying from pala house to press house

Results and Discussion

Effect of Modernization on HVI Fibre Quality Parameters

The lint samples were tested on High Volume Instrument (HVI) for fibre properties. The statistical analysis was carried out and the data presented in **Table 1** and **Table 2** for Ankur- 651 and MCU-5 variety, respectively. No significant difference was observed in the fibre quality parameters. They were 2.5 % span length, uniformity ratio, fineness, strength and elongation for the lint sample collected at the heap (T1) and after pressing (T8). The 2.5 % span length at different processing stages varied between 27.8 to 28.3 mm from heap to press house. Variations in 2.5 % span length were within the tolerance limits of testing. Fibre strength was observed in the range of 21.6 to 22.3 g/tex at different cotton processing stages.

Similarly, no significant changes in fibre quality parameters such as 2.5 % span length; uniformity ratio, fineness and elongation were observed for MCU-5 variety while processing cotton in modernized gin. Variation in the 2.5 % span length was between 31.4 to 32.4 mm, which was in the tolerance limits of testing. Fibre strength decreased marginally from 25.2 to 23.6 g/tex.

Machinery such as pre-cleaner, double roller gin and lint cleaner does not have any adverse effect on the HVI fibre quality parameters. Also, the pneumatic conveying systems for seed cotton and lint at different stages have no affect the HVI fibre quality parameters. Overall effect of modernization on HVI fibre quality parameters was a marginal decrease in 2.5 % span length and strength but within the acceptable range of testing. The uniformity ratio, fineness and fibre elongation was unaffected by the modernization in gins.

Effect of Modernization on Afis Fibre Quality Parameters

The lint samples collected at different stages of cotton processing in modernized gins were tested on AFIS for evaluation of short fibre content (SFC), immature fibre content (IFC), fibre neps, seed coat neps (SCN) and visible foreign matter (VFM). The statistical analysis is presented in **Table 3** and **Table 4** for Ankur- 651 and MCU-5 variety, respectively.

AFIS data showed an increase in short fibre content, fibre neps and immature fibre content for both Ankur-651 and MCU-5 variety. The seed coat neps and the visible foreign matter decreased from one stage to another for both Ankur-651 and MCU-5 variety. For Ankur 651 variety, short fibre content was in the range of 22.1 to 32.2 % from heap to press house. The short fibre content was maximum at the pala house. Immature fibre content (IFC) was between 8.1 to 8.8 %. Fibre neps content increased as the

Table 1 HVI fibre quality parameters for Ankur- 651 variety

2.5 % span length, mm	Uniformity ratio, %	Fineness, mic	Strength, g/tex	Elongation, %
27.8	49	4.1	21.8	4.8
27.7	51	4.1	21.8	5.2
28.3	50	4.1	21.6	5.1
28.1	48	4.1	21.0	4.9
28.1	49	4.1	21.6	5.0
28.1	50	4.1	22.3	5.0
27.9	49	4.1	21.8	5.0
27.6	49	4.1	21.6	5.0

Table 2 HVI fibre quality parameters for MCU-5 variety

2.5 % span length, mm	Uniformity ratio, %	Fineness, mic	Strength, g/tex	Elongation, %
32.2	46	3.1	25.2	6.2
32.1	45	3.1	24.3	6.3
32.2	45	3.1	24.8	6.3
32.4	46	3.1	24.4	6.4
31.7	46	3.1	23.6	6.4
31.4	46	3.1	23.6	6.4
32.2	45	3.1	24.0	6.4
32.0	45	3.1	23.6	6.4

Table 3 AFIS fibre quality parameters for Ankur-651 variety

SFC, n	IFC, %	Fibre neps, cnt/gm	SCN, cnt/gm	VFM, %
28.0	8.3	88	17	2.3
22.1	8.7	77	13	2.3
24.7	8.6	85	14	2.2
27.7	8.1	75	13	2.3
30.5	8.4	97	12	2.3
31.5	8.3	94	15	2.2
32.2	8.8	100	2.3	2.3
28.2	8.8	96	11	2.1

Table 4 AFIS fibre quality parameters for MCU-5 variety Treatment

SFC, n	IFC, %	Fibre neps, cnt/gm	SCN, cnt/gm	VFM, %
35.4	7.4	207	49	0.9
34.7	7.5	179	25	0.6
46.7	7.9	282	34	0.8
42.2	7.7	157	32	0.4
33.6	7.6	156	22	0.3
34.5	7.6	185	29	0.2
40.0	7.9	204	30	0.1
42.2	8.0	217	30	0.1

cotton progressed from one stage to another. Fibre neps content were 88 cnt/gm at heap stage and 96 cnt/gm in the press house. There was a marginal decrease in visible foreign matter (VFM) after processing the cotton. For MCU-5 variety the short fibre content (SFC), as shown by AFIS data, increased from 35.4 to 42.2 %. The neps content increased from 207 to 217 cnt/gm. The visible foreign matter (VFM) decreased from 0.9 to 0.1 %. The visual appearance and the colour grade of the cotton improved significantly.

The ginning, cleaning and baling machinery, along with automatic conveying systems for seed cotton and lint, affected the fibre quality parameters to some extent as shown by AFIS results. Overall effect of modernization on fibre quality parameters was marginally increased in short fibre content, immature fibre content and fibre neps. The visible foreign mater and seed coat neps decreased. The increased neps and short fibre content may be due to the excessive mechanical handling, air current and friction with the inner surfaces of pneumatic pipes.

Overall, the study indicated no significant reduction in fibre quality parameters as tested by HVI and AFIS for the gins modernized as per the TMC guidelines. Modernization minimizes the manual handling of cotton, thus, preventing the contamination to a great extent. Above all, with modernization, ginners can produce trash free clean cotton bales that can fetch a premium price in national and international markets. Modernization by using automatic conveying systems for seed cotton, lint and seed has resulted in increase in production rate in most of the gins. Modernization will help to elevate the reputation of ginners as suppliers of good cotton with trash content as low as 1-2 %. As a result of this, the marketing of bales will become very easy. Cotton ginners should opt in favour of modernization of gins with these added advantages.

Conclusion

Modernization in roller gins does not significantly affect the HVI fibre quality parameters such as 2.5 % span length, uniformity ratio, fineness, strength and elongation. However, a marginal decrease in 2.5 % span length and strength was observed, which was within the acceptable range of testing. Machinery such as pre-cleaner, double roller gin and lint cleaner does not have any detrimental effect on the HVI fibre quality parameters. Also, pneumatic conveying systems for seed cotton and lint at different stages do not affect the HVI fibre quality parameters.

The effect of modernization on AFIS fibre quality parameters was a marginal increase in short fibre content, immature fibre content and fibre neps. The visible foreign mater and seed coat neps decreased with the modernization in gins. Overall, the study indicated no significant reduction in fibre quality parameters as tested by HVI and AFIS for the gins modernized as per the TMC guidelines. The results of the study favor the modernization of gins apart from other advantages of modernization.

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Sleeve Boom Sprayer- I: Design and Development of Tractor Mounted Sleeve Boom Sprayer for Cotton

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Abstract

Air assisted spraying with a sleeve boom sprayer for field crops is a new concept in India. Efforts have been made to design and develop a sleeve boom sprayer which could be operated by a 30-35 hp tractor. The axial flow blower was developed with a capacity of 3.1 m^3/s. Three types of blades; cambered, tapered and flat undersurface were designed and fabricated with FRP and aluminium. A common aluminum hub was developed to accommodate ten blades at a time with provision to adjust the blade stagger angle. The boom, sleeve and hydraulic system for the sprayer were also developed. A tapered sleeve was designed and made with fiber reinforced PVC material in order to get uniform air velocity at each outlet.

Introduction

Cotton (Gossypium herbacium) is a major cash crop in India and is grown on 7 million ha every year. It is highly susceptible to insets such as pink ball worm, ball borer, aphids and leaf minor. Over head spraying onto the leaf surface usually results in reduction of coverage on lower leaves and the underside of leaves due to heavy vegetative growth and interminglement of adjacent plants. The present indiscriminate use of pesticides has resulted in several risks and ill effects such as ecological imbalance, health hazards, resistance in pest and insects, resurgence of minor pests, emergence of newer pests and environmental pollution (Ramarethinam, 1998). Integrated pest management (IPM) has been developed out of the need for a sustainable crop protection strategy against the background of increasing pesticide use and deleterious effect of residues on environment (Abdul, 1998). In the present conventional spraying system, manual and power operated sprayers are often used for field corps and orchards. Pest control could not reach the expected level because of the drift problem. The windborne toxic chemical spray released from sprayer nozzles caused damage to the environment (Anonymous, 1997). Air sleeve boom sprayers are very well accepted in developed countries but, for a country like India, it is new concept. Manor *et al.* (1989) claimed that high drift reduction, improved canopy penetration and faster application rate gives quick,

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easy pest control with air assisted sleeve boom spraying. The sleeve boom spraying technology is based on air assisted spraying. This system essentially consists of a blower, nozzles, pump and sleeve or duct. The sleeves, made of PVC material, are inflated with the air mass generated by blower. The sleeve has a series of holes at the bottom for delivering air. The spray droplets produced by nozzles are transported to a target through a stream of air coming out of sleeve orifices which results in better control over spray droplets and deposition (Manor, 1989). This sophisticated machine needs 52-59 PTO kW power (70-80 PTO hp tractor) to operate. In India 18-22 PTO kW (25 to 30 PTO hp) tractors are most commonly used. A very few research studies have been made on air sleeve boom spraying system for orchards. However, no systematic work has been done on the sleeve boom sprayer for field crops in India. Therefore, efforts have been made to develop a sleeve boom sprayer for the most commonly used tractor (30-35 hp) in the country. The research work on the sleeve boom sprayer was undertaken at ASPEE Agricultural Research and development Foundation, Mumbai.

Design of Sleeve Boom Sprayer

The sleeve boom sprayer worked on the air displacement theory and air played an important role in the spraying system. Efforts were made to develop an air delivery system considering canopy structure of the foliage crop. The major components of the sleeve boom spraying system were the blower, sleeve, spraying nozzles and pump. A main frame was fabricated to mount the chemical tank, control panel and blower assembly. The blower generated the required volume of air and directed the air flow into the sleeve. A rectangular blower casing with two outlets was provided to both its sides for fixing two sleeves. Air from the blower was conveyed and distributed through two sleeves with multiple orifices to achieve an airflow pattern covering the canopy. The system was developed to obtain the required effective penetration of spray into the dense foliage canopy with an air discharge velocity that would have the least air blast damage at the target. The axial flow blower and two tapered sleeves were developed so that air coming out of the sleeve through a series of holes would be sufficient to cover the plant canopy. The sleeve was designed to produce an air curtain along the length of boom and to distribute air uniformly. The boom frame was made to support the air sleeve and hydraulic nozzles for a final delivery of air-pesticide mixture onto target. The hydraulic system was also developed to adjust the spraying and folding of the boom for easy transportation. The blower was the heart of the air assisted spraying system. Hence, the sleeve boom sprayer design was divided into

- Blower design
- Design of sleeve boom
- Design and selection of hydraulic system

Assumptions

Design of the air assisted sprayer was based on air displacement. Hence, sprayer size, rate of travel and volume of plant were basic parameters for blower design. The sprayer size needed for air assisted spraying for a particular crop depended on the volume of the plant. The idea was that all air pockets contained within the plant were driven out completely and replaced with the air laden with chemical. Cotton crop was considered to have a cylindrical canopy for this study. The crop parameters for sprayer size design were considered as

- The maximum average height of the crop at the time of spraying (H_m), 1,100 mm
- The minimum average height of the crop at the time of spraying (H_i), 450 mm
- The maximum average diameter of the plant canopy (D_m), 900 mm
- The minimum average diameter of the plant canopy at the time of spraying (D_i), 450 mm
- Ground clearance of crop at maturity, 150 mm
- Crop spacing, 900 × 900 mm.

A machine forward speed for spraying was in the range of 0.33 to 1.95 m/s (Anonymous, 1984, Hunt, 1991) depending on the crop foliage and growth. Spraying speed at maximum and minimum crop height was 0.42 m/s and 1.25 m/s, respectively. The power available for operating a sleeve boom sprayer from a Mahindra - B 275 tractor was 11 kW. The axial flow blower and its components were designed from assumptions and formulae monograms by Wallis (1983). The parameters assumed for the blower design were

- Impeller speed (N), 2,200 rpm
- Impeller diameter (d_t), 630 mm
- Impeller hub diameter (d_h), 280 mm
- Boss ratio (ν), 0.444
- Blade angle of twist, 8º
- Lift co-efficient (C_L), 0.75
- Maximum pressure attained at blower exit at maximum blower efficiency, 2,093 N/m^2
- Number of blower outlets, 2
- Diameter of blower outlet, 0.26 m.

Blower Capacity

The blower design included design of impeller blades, hub casing and diffuser. The impeller consisted of the required number of blades fitted on the hub. Based on the earlier research by Hiwase (1990), Hunt (1999) and Jadhav (1998) parameters related to cotton crop were considered. The capacity of axial flow blower and air velocity were 3.1 m^3/s and 31 m/s, respectively. The capacity of the blower was calculated by the equations below.

The volume of cotton plant

$= (\pi / 4) \times D_m^2 \times H$ ··············· (1)

$= 0.604\ m^3$

Assuming 10 percent volume occupied by branches and leaves, the volume of cotton plant would be

$V_c = 0.544\ m^3$

Sprayer size = [Rate of travel (m/s) × vol.of plant (m³) × No.of plants to be sprayed at time] / Crio spacing (m) .... (2)

$$= \frac{0.42 \times 0.544 \times 12}{0.9}$$

$= 3.1\ m^3/s.$

Design of Blades

According to Wallis (1983), the cambered type air foils are of uniform thickness and very simple for the fabrication. Their operational characteristics are better and the peak efficiency is good for high quality inlet flow. Flat under surface type blades are efficient but suitable for low pressure rise. Three different shapes of airfoil, viz. cambered type (C_a), flat under surface type (FU) and tapered (T_a), similar to cambered type but with the leading and trailing edge made sharp, were selected for the blade design. These three types of blades were designed by following design considerations and guidelines by Wallis (1983) and fabricated with two different materials, viz. FRP and aluminum, considering their properties (Anonymous, 1985) and the limitations of power availability.

The mean axial velocity, total theoretical pressure required at impeller, pressure loss coefficient and local swirl coefficient were determined using formulae from Wallis, 1983. These values were used to determine mean blade angle, blade solidity and camber angle. The radius of curvature was determined on the basis of chord length and camber angle. With these dimensions, the wooden mould was prepared and finally ten blades of FRP and aluminium were fabricated. The various formulae used to obtain these dimensions are discussed as below. Symbols used in these relationships were:

A_e = Area of blower exit, m²
A_s = Swept area of impeller blade, m²
B_m = Mean blade angle, degree
b/C = Blade camber
C = Chord length, m
ε_s = Local swirl coefficient
H_{th} = Total theoretical pressure required at impeller, N/m²
K_{th} = The total pressure loss flow coefficient
λ = Local flow coefficient at hub or tip
N = Impeller speed, rpm
P = Maximum pressure attained at blower exit, N/m²
Q = Discharge, m³/s
R = Impeller radius, m
R_c = Radius of curvature, m
r = Blade radius, m
σ = Blade solidity
ρ = Air density at standard temperature and pressure, kg/m³
θ = Blade camber
ν = Boss ratio
V_a = Mean axial velocity, m/s

Mean Axial Velocity (V_a)

The mean velocity of air through the blower blades is dependent upon the air discharge rate, impeller radius R and boss ratio (ν).

$$V_a = \frac{Q}{(1 - \nu^2)\,\pi R^2} \quad \text{.....................} (3)$$

$$V_a = \frac{4}{(1 - 0.444^2)\,\pi\,(0.63 / 2)^2}$$

$= 16.00\ m/s$

Total theoretical Pressure required at Impeller (H_{th})

$H_{th} = P\,(A_e / A_s)^2$ ······················· (4)

$= 2093\,(0.1297 / 0.2501)^2$

$= 562.88\ N/m^2$

Total Pressure Loss Flow Coefficient (K_{th})

$$K_{th} = \frac{H_{th}}{0.5\,p\,(V_a)^2} \quad \text{...................} (5)$$

$$K_{th} = \frac{562.88}{0.5 \times 1.225 \times (0.16)^2} = 3.59$$

Local Flow Coefficient (λ)

$\lambda = V_a / 2\,Nr$ ····························· (6)

$$\lambda_h = \frac{16 \times 60}{2 \times \pi \times 2000 \times 0.14}$$

$= 0.5$ (at hub)

$$\lambda_t = \frac{16 \times 60}{2 \times \pi \times 2200 \times 0.315}$$

$= 0.22$ (at tip)

Local Swirl Coefficient (ε_s)

$\varepsilon_s = K_{th}\,\lambda / 2$ ····························· (7)

$$(\varepsilon_s) \text{ at hub} = \frac{3.59 \times 0.5}{2} = 0.897$$

$$(\varepsilon_s) \text{ at tip} = \frac{3.59 \times 0.22}{2} = 0.395$$

Mean Blade Angle (B_m)

$B_m = \tan\,[(1 - 0.5\,\varepsilon_s\,\lambda) / \lambda]$ ······· (8)

$$\beta_m \text{ at hub} = \tan^{-1}\frac{1 - 0.5 \times 0.897 \times 0.5}{0.5}$$

$= 57.20^0$

$$\beta_m \text{ at tip} = \tan^{-1}\frac{1 - 0.5 \times 0.395 \times 0.22}{0.22}$$

$= 77.04^0$

Blade Solidity (σ)

For the calculated values of ε_s (0.897) and λ (0.5), σ was taken as 1.23

Chord Length (C)

$$C = \frac{2\pi r\sigma}{n} \quad \text{................................} (9)$$

$$C = \frac{2\pi \times 14 \times 1.23}{10}$$

$= 0.1082$ m, say 110 mm

Chord length (C) at the tip was considered as 90 mm on the similar concept of Das (1997) and Patil (1997).

Blade Camber Angle (θ)

$$\theta = \frac{b / C}{0.0021} \quad \text{.............................} (10)$$

Considering the camber ratio, 7 % at hub and 4 % at tip side,

$$\theta \text{ at hub} = \frac{0.007}{0.0021} = 33.33^0$$

$$\theta \text{ at tip} = \frac{0.004}{0.0021} = 19.0^0$$

Radius of Curvature of Camber Line (R_c)

$$R_c = \frac{C}{2 \sin \theta / 2} \quad \text{......................} (11)$$

$$R_c \text{ at hub} = \frac{110}{2 \sin (33.3 / 2)} = 192 \text{ mm}$$

$$R_c \text{ at tip} = \frac{90}{2 \sin (19.0 / 2)} = 273 \text{ mm}$$

Thickness (t) of Blade

Thickness (t) of blade Ca and Ta was calculated as 4 mm at the hub and 3 mm at the tip assuming thickness to chord ratio as 3.5 percent and 3 percent while, for FU blade, it was selected as 15.5 mm at the hub and 9.3 mm at the tip, assuming thickness to chord ratio as 13.5 percent and 9.5 percent of the chord length (Wallis, 1983). Hence,

For cambered and tapered type blade:

$t_h = 4$ mm (at hub)

$t_t = 3$ mm (at tip)

For flat undersurface type blade:

$t_h = 15.5$ mm (at hub)

$t_t = 9.3$ mm (at tip)

Design of Blade Collar and Hub

In each type of blade, a circular collar to interlock with the aluminium hub was provided at the inlet end. The design dimensions of the collar were determined considering the centrifugal force (f_c) of the individual blade of mass (m) as 600 g and operated at impeller speed (N) of 2500 rpm. The effective mass of each blade was assumed to be concentrated at a radial distance (R_c) of *0.2275 m [14.0 + (31.5 − 14 / 2)]* and the centrifugal force (f_c) was calculated as follows

$$(f_c) = m\omega^2 R_c \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

$$= 0.6 \left[\frac{2\pi \times 2500}{60}\right]^2 \times 0.2275$$

$$= 93555.63 \text{ N}$$

Assuming the factor of safety as 2 and permissible tensile stress of FRP as 600 MN/m^2, the diameter of the collar was calculated considering the blade in direct shear. Hence,

$$f_c = \frac{600 \times 10^6 \times \pi d^2}{2 \times 10^4 \times 4}$$

$$d = 1.99 \text{ cm} = 19.9 \text{ mm.}$$

A safe diameter of the collar was taken as 20 mm.

Finally, the designed dimensions of the blades and sectional profiles of the blades are shown in **Figs. 1** and **2**.

A circular collar was made at the hub side to keep the blades in the cavity of the hub. A common aluminium hub with a diameter of 280 mm to accommodate ten blades at an angular spacing of 36º was developed for conducting the experiment using an impeller of different blades. The hub was made in two symmetrical halves for easy placement of blades. The thickness of each half was 10 mm (**Fig. 3**). The conical shaped blower inlet in was fabricated with MS sheet. To reduce the mean velocity in a steady manner, recover the static pressure and create subsequent difference in dynamic pressure, two conical diffusers with increasing cross sectional area towards ends, were fabricated. The divergent angle was kept at 5.5º (Wallis, 1983). The diffuser plates were bent toward the two outlets of blower.

Diffuser and Blower Casing

The blower casing, inlet, diffuser, cylinder and outlet were fabricated with M.S. sheet. The design dimensions of air inlet, cylinder, and length, width and height of the body were as shown in **Fig. 4**. For achieving higher velocity at blower outlet, the diameter of blower outlet was selected as 260 mm. A bearing

Fig. 1 Design details of impeller blade

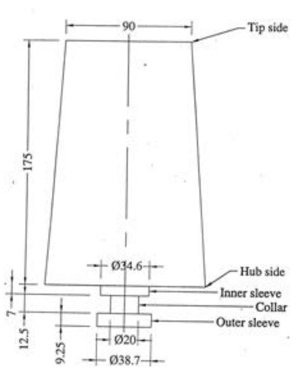


Fig. 2 Sectional profiles of diffrent types of blade

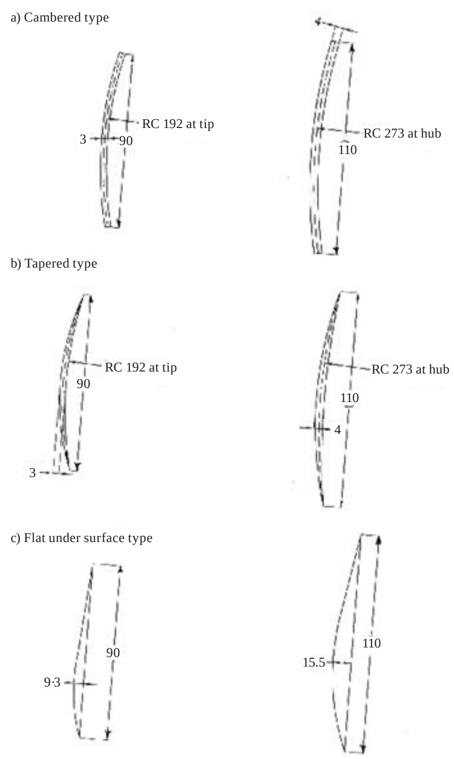
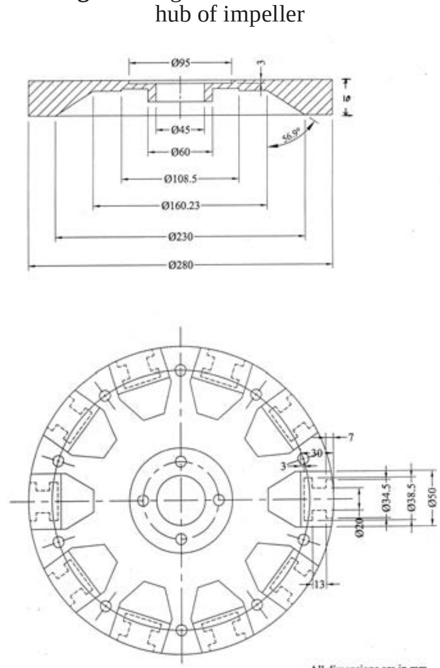


Fig. 3 Design details of aluminium hub of impeller



block of 110 mm diameter was fixed for mounting the impeller hub inside the blower casing.

Design of Sleeve Boom

A horizontal flexible air duct was designed to generate an air curtain with a uniform air velocity profile throughout the length of boom by tapering the duct (sleeve) towards the close end. The friction losses incurred in the tapered duct were minimum as compared to the stepped reduction of the cross sectional area towards the close end according to Bruce (1984). This was achieved by keeping the air exit per unit length of the duct constant and by decreasing its cross section from blower outlet to the dead end of the duct.

Let L be the length of sleeve equal to swath width and D its diameter at the inlet (at the exit of the blower). The other end of sleeve is closed with 'n' number of orifices of uniform cross section throughout its length (**Fig. 5**). The air is blown into the duct from the blower and forced out through the orifices. The frictional and gravity effects are considered as negligible. Since the air was required to have uniform distribution of air along the duct, it was decided to taper the duct so that the vertical air velocity will remain constant along its length (Hall, 1970). Thus, to maintain uniform distribution of air along the length of the duct, the diameter of the duct at different cross sections (D_x) was determined as shown below.

Let and $D_o = 0$ at $X = L_s$, where D_o is the diameter of the duct at $X = 0$.

The quantity of air entering the duct can be calculated from continuity equation as

$$Q = A \times V \quad (13)$$

The cross sectional area at $X = 0$ and diameter D_o is

$$A = \frac{\pi}{4} \times D_o^2 \quad (14)$$

The total volume of air entering the duct is equal to the total discharge through out its length.

$$Q = Q_d \times L \quad (15)$$

where, Q_d = total discharge from duct through out the length of the duct, m^3/s.

The quantity of air passing the section 'X' is calculated as

$$Q_x = A_x \times V \quad (16)$$

where,

Q_x = total discharge through the section X,

A_x = cross sectional area at section X.

The volume of the air passing the section X is equal to the total discharge through the remaining length of duct.

$$Q_x = Q_d \times (L - X) \quad (17)$$

Eqns. 13 and **17** lead to

$$Q_d \times L = V \times \frac{\pi}{4} \times D_o^2 \quad (18)$$

and

$$Q_d \times (L - X) = V \times \frac{\pi}{4} \times D_X^2 \quad (19)$$

The ratio of **Eqns. 17** and **18** is

$$\frac{Q_d \times L}{Q_d\,(L - X)} = \frac{V \times \pi / 4 \times D_o^2}{V \times \pi / 4 \times D_X^2}$$

Hence, $\dfrac{L}{L - X} = \dfrac{D_o^2}{D_X^2}$

Therefore, the diameter of the duct at section X is

$$D_X^2 = D_o^2\,[(L - X) / L]$$

$$D_X = D_o\,(1 - X / L)^{1/2} \quad (20)$$

The above equation gives the relationship between the length of duct (air sleeve) and its diameter at different section tapering towards the close end. The diameter of sleeve obtained at different sections is shown in **Table 1**.

For the laboratory test, the tapering air duct system of 260 mm diameter at the inlet and 5 m length coverging to zero diameter towards the dead end and made of fiber-reinforced PVC was sewed (**Fig. 6**). Its large end was fixed to one of the blower outlets to distribute air over the full length of boom. At the bottom of the sleeve, the orifices of 40 mm diameter, spaced at a 90 mm, were continuous throughout

Table 1 Diameter of sleeve obtained at different sections

Particulars	Dimensions
X = 0.5	260 mm
X = 1.0	260 mm
X = 1.5	250 mm
X = 2.0	230 mm
X = 2.5	210 mm
X = 3.0	180 mm
X = 3.5	160 mm
X = 4.0	130 mm
X = 4.5	90 mm
X = 5.0	0.0 mm

Fig. 4 Design details of inlet, blower casing and diffuser

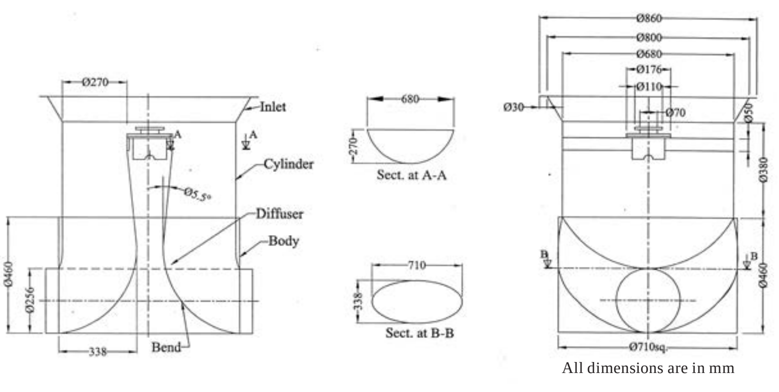
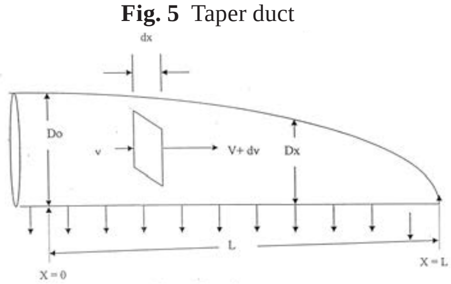


Fig. 5 Taper duct



its length. The developed air sleeve was mounted on the boom with the help of circular rings. Hollow Cone Mist Spray Nozzle (HCN/PD-10900) was selected for the experiment (spray angle 80º, discharge rate 150 cc/min). In this study, spacing of nozzles was 450 mm as used in a conventional boom sprayer.

The boom for the sleeve boom sprayer was made of *25.4 mm × 25.4 mm × 5* mm M.S. angle. Four rings made of M.S. rod of 10 mm diameter were joined on the boom to facilitate holding the flexible air duct. The nozzles were mounted on straight G.I. pipe along the length of horizontal air duct. The boom has a frame to support the air sleeve and hydraulic nozzles to make the final delivery system for the air liquid?pesticide mixture onto the target. A view of the boom in folded condition is shown in **Fig. 7**.

Design and Selection of Hydraulic System

The mounted type sleeve boom sprayer was designed for a 35 hp tractor. The facility provided for vertical movement of the sprayer boom and blower assembly to help in increasing and decreasing the height of spraying above plant canopy and also for horizontal movement for folding the booms for ease of sprayer transportation (**Fig. 8**). The hydraulic system consisted of a reservoir to hold hydraulic oil, a pump to force the liquid through the system, a valve to control direction of flow, an actuator to convert hydraulic energy into mechanical energy to do useful work and piping which carried the liquid from reservoir to actuators. The hydraulic pump used on the 35 hp tractor was 5 hp, therefore, it was for operation of the additional hydraulic system attached on the sprayer. Based on the considerations and following the guidelines by Thakare (2004), the components of the hydraulic system were designed and selected from commercially available hydraulic components. In the air sleeve boom sprayer one movement was required for vertical lifting of boom and blower assembly and two movements for folding the two boom arms of the sprayer. A three way direction control valve was required and a commercially available three way direction control valve model CH-1l No.2 R22 DDD IL 2L-3 spool was selected.

The lift of the boom depended on the total height of the plant at full grown stage and maximum height to which the boom was to be lifted above the plant canopy. The total height of boom from the ground surface was up to 1800 mm. The cylinder had to lift the total load of boom and blower assembly vertically. The weight of fan, its mounting, blower casing, boom arm, boom frame and other accessories were 300 kg. The weight of the assembly was used to design the actual size of the main vertical cylinder. The stroke length, working pressure and speed of advancement of piston to lift boom and blower assembly were 800 mm, 70 kg/cm^2 and 4 m/min, respectively.

The area of piston was determined by the equation,

$$F = P \times A \quad \text{.............................} \quad (21)$$

$$A = 17.14 \ cm^2$$

where,

F= *force, kg*

P = *pressure, kg/cm*^{2},

A = *area, cm*^{2}

The flow rate of the oil in the system was a function of the speed of the piston and volume of oil filled in the cylinder.

$$Q = \pi \times r^2 \times L \quad \text{.........................} \quad (22)$$

$$= 20.096 \ l/min$$

where,

r = *radius of piston,cm*

L = *stroke length, cm*

Fig. 6 Tapering air sleeve with orifice at its bottom side

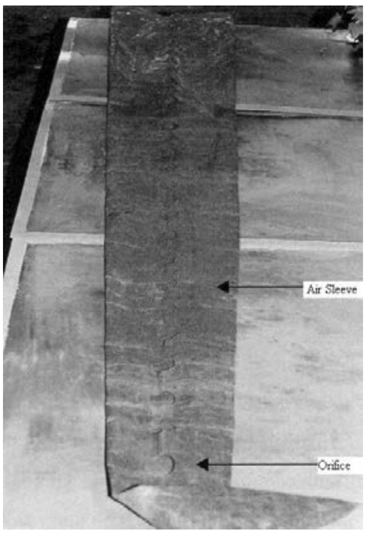


Fig. 7 Rear view of sprayer showing two cylinders for folding of boom

Fig. 8 View of folder air sleeve boom to facilitate transportation

Fig. 9 Piston position during open boom

A double acting hydraulic cylinder VDL 80-56 with an 850 mm stroke length, 80 mm piston diameter and 56 mm piston rod diameter was selected for vertical movement of the boom assembly. For horizontal movement of the boom, the force required to fold the boom was very small. Hence, a double acting cylinder with a 52 mm bore and 25 mm piston rod diameter was selected. A 12.7 mm inner diameter hose of with a maximum operating pressure of 140 kg/cm^2 was selected for the hydraulic system to be mounted on the air sleeve boom sprayer. As the oil requirement was very low for few moments, it was decided to use the oil reservoir of the hydraulic system of the tractor during the whole operation. The piston position for boom opening is shown in **Fig. 9**.

Power Transmission Unit

The power transmission unit was used to drive the blower and HTP pump. The power was taken from the tractor PTO by means of propeller shaft and transmitted to the blower through a gear box. A V-grooved pulley was provided on the shaft of the gear box trough which the power was taken to operate HTP pump.

Accessories

A horizontal triplex pump (HTP) was used to generate the pressure on the spray fluid, which worked in an oil bath and produced a maximum discharge of 35 l/min at a pressure of 28 kg/cm^2. It was equipped with a pressure control valve to stabilize the pressure. The fluid control system consisted of a by-pass valve, pressure gauge, pressure regulator valve, delivery and agitator lines.

Testing the Sleeve Boom Sprayer

The performance of the blower of the sleeve boom sprayer was evaluated for blower speeds of 1,841 rpm, 2,035 rpm, 2,133 rpm and 2,362 rpm, for five stagger angles of 8º, 16º, 2º, 32º, and 36º and an impeller of cambered, tapered and flat undersurface type with two different materials; FRP and aluminium in the wind tunnel. The performance of the sleeve was evaluated for different sleeve angles viz. -15º, 0º, 15º and 30º and for nozzle angle of 25º, 35º and 45º in the laboratory. The spray obtained through the nozzles was collected on glossy papers placed on the cotton plants under false floor arrangement. The best blower speed, impeller and blade stagger angle, sleeve angle and nozzle angle were selected during the field evaluation of the sleeve boom sprayer. Its performance evaluation will be reported subsequently.

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Development and Evaluation of a Prospective Grader for Spherical Fruits

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Abstract

A fruit grader based on the principle of changing the flap spacing along the length of movement of fruits was designed, developed and tested. The main components of the fruit grader were grading unit, elevator feeding unit and inspection plat form. The grading unit consisted of hollow pin chain and matching sprockets, steel flaps and rollers, wheel track, power source, power transmission system and fruit collection tray. The elevator feeding unit provided for constant and uniform feeding of fruits into the grading unit. The inspection platform provided for removal of damaged, diseased and unwanted fruits before they are fed to the elevator feeding unit. Cushioning material was glued to the inspection platform, collecting tray and flaps to avoid impact damage at the time of grading. A 2.25 kW 3 phase electric motor with output speed of 50 ± 5 rpm was used to operate the grader. The grader had the provision to separate fruits into four grades by changing the flap spacing between 35 to 140 mm by adjusting the height of wheel track. Testing the fruit grader showed overall grading efficiency of 91-94 % for sweet lemon, orange, sapota and apple fruits. The capacity of the grader varied from 3.80-4.00 t/h at a grading conveyor speed of 6 m/minute with no bruising or cutting damage to the fruits while grading. The cost of operation of the grader was Rs. 800/tonne.

Introduction

India accounts for 10.1% of the total world production of fruit crops and ranks second with the production of 45.47 million tonnes (Singhal, 2003). A group of unit operations like washing, drying, grading, waxing, packaging and pre-cooling are performed after harvesting the fruits before they reach the ultimate users. In this group of unit operations, grading is one of the most important operations, which involves overall balance assessment of all these properties of the fruits, which affects its acceptance as food and as working substance for the processor (Mangaraj and Varshney, 2006). It adds value of the product and gives better economic gain to the producer. Grading of fruits and vegetables on the basis of size and shape is important for marketing uniform high quality produce (Varshney *et al.*, 2002). At present, fruits are graded manually, which is labour intensive and time consuming. Besides, manual grading has a wide variation in the sizes of the graded fruit. In view of above considerations a mechanical fruit grader is a useful option. Mechanical grading of the fruits and vegetables is done based on weight, size and shape, while principle of optics is involved in colour sorting.

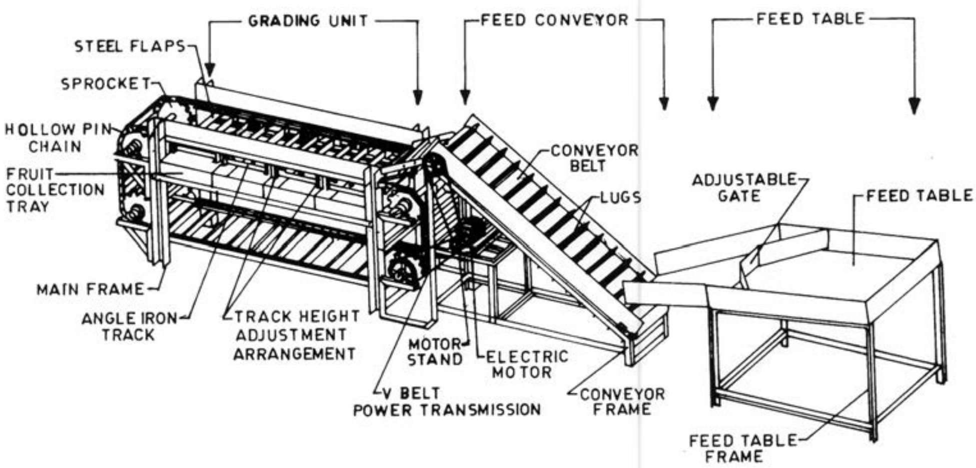
Various researchers have developed machines for sorting fruits and vegetables into different grades. Omre (1999) developed a grader that grades the fruits and vegetables based on their unit weight. Grading of the fruits based on weight involves weighing of each fruit precisely, which limits the capacity. Sometimes results are not consistent when the produce is sorted by weight (Brennan *et al*., 1976). Grover and Pathak (1972) developed a wire belt potato sizer capable of sizing the potatoes into four grades. The bruising damage to the potatoes was observed due to the rollers provided at the end of the sizing unit. Verma and Kalkat (1975) designed and developed an expanding pitch rubber spool potato sizer. It was used for sizing potatoes, onions and fruits of different types. In this machine potatoes were not separated into desired sizes as overriding occurs during the grading process. Singh (1980) studied the performance of differential belt speed expanding pitch type potato grader. The main components of the grader were feed conveyor, frame, grading unit, collection platform and power transmission unit. The maximum separation efficiency at optimum grader shaft speed of 35 rev/min, belt speed 4.4 m/min and a feed rate 1.7 to 2.4 t/h of was 87 %. A mango grader developed by Mandhar and Senthil Kumaran (1999) sorts the fruits on the basis of rolling of mango around the axis of minimum mass inertia. The fruits were fed at the higher end of the machine and roll down under gravity in a expanding opening created by a set of rolls placed divergently. The machine separated mangoes into four grades in the size range of 50-56, 57-63, 64-70 mm and > 70 mm. O'Brien (1968) developed a field machine for fruit sizing, sorting and filling bins during harvest that had a sorting conveyor, sizing conveyor and bin filling unit. The machine was used for grading pears, peaches and gherkins. Bruter *et al.* (1983) developed equipment for sorting fruits and vegetables according to size that comprised of a 2 level chain conveyor with movable rollers. Design features simplify alteration of the rollers location when calibration apertures were to be enlarged/ reduced. Ingle (1997) developed a simple electric divergent roller grader suitable for lemon, sapota, onion, potato, pomegranate and like fruits and vegetables. The machine carried a number of rotating rollers with alternate rollers rotating in opposite directions. The rollers were arranged so that the gap between them increased symmetrically causing smaller fruits to drop through at the end while larger fruits moved further along the rollers. Sized fruits passing between the rollers were collected in separate compartments. Keeping these factors in view, a stepwise expanding pitch fruit grader based on the principle of changing the flap spacing along the length of movement of fruits was designed and developed. Grading of fruits was based on size and shape. The advantages of this fruit grader were high level of versatility, high capacity, minimal handling and tumbling of the fruit with no damage to the fruit while grading.

Materials and Methods

Design of Fruit Grader

A step wise expanding pitch fruit grader based on the principle of changing the flap spacing along the length of movement of fruits was design. The proposed grader was to be used for sizing of fruits with equivalent diameter ranging from 35 to 140 mm that were nearly round. The spacing was decided after the measurement of geometric diameter of the fruits, primarily apple and citrus. The main components of the fruit grader were grading unit, elevator feeding unit and inspection platform. The grading unit consisted of hollow pin chain and matching sprockets, steel flaps and

Fig.1 Schematic diagram of the stepwise expanding pitch fruit grader



rollers, wheel track, power source, power transmission system and fruit collection tray. It was desired to grade various fruits in four grades by small adjustment, minimizing damage to fruits by with cushioning material on the inspection platform, flaps and the collection tray where the fruits drop. Visual inspection of was made for damaged and sub standard fruits before mechanical separation for size. A fruit elevator-cum-feeder was provided for uniform feeding of fruits. The capacity of the grader was 4 t/h with a power requirement of 2.25 kW.

Design and Selection of Various Components

Grading Unit

The various components of the grading units were hollow pin chain, matching sprockets, steel flaps and rollers, wheel track, power source, power transmission system and fruit collection tray. In order to grade the fruits in the size range of 35-140 mm, a 75 mm pitch hollow pin chain was chosen. Forty five 500×118 mm flaps were designed to be fixed in the hollow pin groove of the chain, alternatively, to get the maximum spacing of 140 mm between the two flaps. Flaps of stainless steel were coated with a rubber sheet to avoid damage of the fruits. The linear speed of chain was 6 m/min. The chain was operated from sprockets powered by a 2.5 kW electric motor.

Dimension of Grading Assembly

The width of the grading unit was 500 mm as determined from ergonomic considerations. The effective length of the grading unit was calculated by providing four exposures of spacing between two flaps for a particular fruit to fall in a particular grade. However, the number of exposures could be varied depending upon fruit lots.

Length of the grader (L) $= N \times 2 \times P \times F$

where

L = length of grader, m

N = number of grades required

P = pitch of chain, m

F = number of openings for a particular grade.

Thus, $L = 4 \times 2 \times 0.075 \times 4 = 2.40$ *m.*

Fruit Collection Tray

The collection tray had four spouts for four fruit grades. An inclination of 6º was was adequate for free flow of fruits. The collection tray was cushioned with poly foam and rubber sheet to avoid damage to the collected fruits.

Power Transmission System

A geared, 2.25 kW electric motor with an output speed of 50 rev/min was used with speed reducing belts and pulleys for a conveyor speed of 6 m/min.

Grader Capacity

Average size of the fruit = 70 mm

The theoretical number of fruits that could be accommodated on 500 mm wide conveyor chain = 500/70 = 7.0

Considering spherical shape and grader speed of 6 m/min the theoretical volume of fruits that could be handled in one hour was

$$q_t = n \times A \times v$$

where

q_t = *theoretical volume per unit time,* m^3/h

n = *area of cross section of fruit,* m^3

A = *area of cross section of fruit,* m^2

V = *velocity of conveyor, m/h*

Thus $q_t = 7 \times (\pi / 4) \times 0.07^2 \times 6 \times 60 = 9.702\ m^3/h.$

Considering 50 percent effective space occupied by the fruits since all the fruit will not be in close contact:

$$q_a = q_t \times 0.50$$

where

q_a = *actual volume rate*

q_t = *theoretical volume rate,*

and

$$q_a = 9.702 \times 0.50\ m^3/h$$

The capacity (C) of the grader was $C = q_a \times \rho$, where ρ is the density.

Therefore,

$$C = (9.702 \times 0.50 \times 915) / 1000 = 4.44\ ton/h.$$

Design Considerations of Elevator

The width of the elevator was 500 mm and was equal to the width of the grading system for proper feeding. For proper conveying of fruit, the lug height was 80 mm to hold even larger fruit. Spacing between lugs was 150 mm so that a single layer of fruit was obtained. The angle at which the belt conveyor could operate was determined by the angle of repose of the material and the friction between belt and material. Maximum recommended slope for grain elevators was 20-22º and for cereals it was 16-22º. Since the fruits are larger size with less possibility of falling, a maximum angle of 25º with the horizontal was considered for the elevator feeder. The material for the lugs was stainless steel with rubber coating and the elevator belt was a 3-6 ply rubber sheet 500 mm wide and 12 mm thick.

Design Considerations of Inspection Platform

The inspection platform to sort the damaged and unwanted fruits manually consisted of following components:

Rear fruit feeding trough = 1,500 mm × 1,200 mm with 200 mm high wall

Inclination of the trough = 4º adjustable from 3º to 15º (determined on the basis of free movement of fruit)

Front inclined trough - trapezoidal section: Maximum width: 1,200 mm

Minimum width: 550 mm

Length: 470 mm

The surface of the platform was coated with rubber sheet to avoid damage to the fruit.

Development of Fruit Grader

Grading Unit

The mainframe of grading unit was made from 1*00 mm × 50 mm ×*

5 mm mild steel channel. The effective length of the grader was 2.24 m by providing four exposures of spacing between two flaps for a particular fruit to fall in a particular grade. The width of the frame was 680 mm and effective width of the grading bed was 500 mm. Eight angle iron brackets were welded to the frame at the front top and bottom and back top and bottom on both sides. Shafts of 50 mm diameter were mounted on brackets with pedestal bearings. Eight sprockets of 301 mm diameter were keyed on the driven and drive shafts. Two tracks of hollow pin roller chains of 75 mm pitch were mounted on eight sprockets supported on each end, thus, making a continuous conveyor. Steel flaps were welded with 10 mm diameter steel rods on both ends. Upper end of the flap steel rod was fixed into the chain's hollow pins alternatively on both sides. At the lower end of the flap, resting wheels of high density polyethylene (HDPE) were mounted on both ends of the steel rod with circlips. The steel flaps along with a hollow pin conveyor chain formed the grading bed. The resting wheels of the flaps moved on 50 mm × 50 mm × 5 mm MS angle iron tracks. These angle iron tracks were supported by track height adjusting mechanism. This mechanism consisted of a nut and bolt welded with bush on head end, which fixed the angle iron track at the required vertical position. The position of the angle iron tracks along both sides of the sorting assembly determined the vertical slope of the flaps which gave the required opening between the stainless steel flaps. As the angle-iron track surface was lowered, the vertical slope of the flaps increased and so did the spacing between the flaps. This arrangement provided great flexibility to adjust the flap spacing for grading of fruits in any grade between minimum and maximum spacing of 45 to 140 mm. The spaces between the stainless steel flaps were such that the undersize fruits passed through, and the larger fruits were carried over to the next higher grade. The fruits that were small enough to pass through the space between the steel flaps fell on a cushioned fruit collecting chute. The level of each angle iron track remained horizontal for four spaces to provide ample time for each size fruit to fall through in its appropriate collecting chute.

Fruit Collection Tray

The fruit collection tray of 2 m × 0.94 m was made of 1.5 mm thick stainless steel sheet. The collection tray was partitioned into four chutes with a 150 mm high wall to collect different grade fruits into separate containers. The collection tray was cushioned with 12 mm thick poly foam and 1 mm thick rubber sheet glued on poly foam as well as on the stainless steel sidewalls to prevent the fruit from bruising. The collection tray was supported with angle iron and welded at a slope of 7º with the horizontal, which facilitated the flow of materials. The different fruit grades were collected in four different chutes and packed in containers.

Feed Elevator Conveyor

The fruit grader was provided with a belt feed conveyor for constant and uniform feeding to the grading unit. The frame was made of *100 mm × 50 mm × 5 mm* channel. The height of the frame was 1.4 m from the ground to match with the height of grading unit. A 500 mm wide continuous rubber belt was mounted on two pulleys. The belt was supported with three 50 mm diameter idler rollers to prevent sagging. The angle of inclination/slope of feed conveyor was 25º. Stainless steel sheet lugs of *500 mm × 75 mm* were fixed on the rubber belt at a distance of 150 mm to carry the fruit. Lug height of 75 mm was determined from the maximum diameter of fruits to be graded. Lugs were coated with rubber sheet and rubber beading was placed on the top edge to avoid fruit damage. Stainless steel side plates 75 mm high were provided on either side of the feed conveyor belt to avoid the fall of the fruits to the sides. Fruits fed from the feed table to the feed conveyor were dropped on to the fruit grading bed.

Fig. 2 Stepwise expanding pitch fruit grader

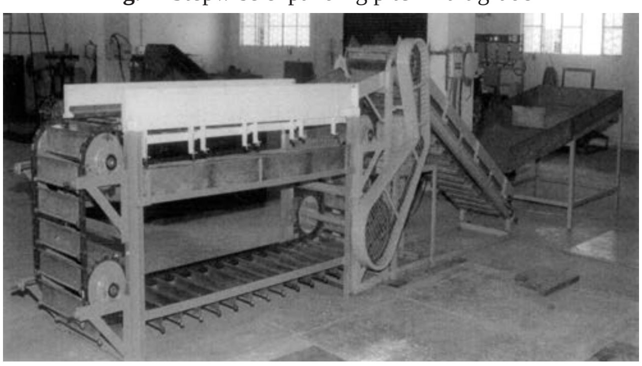
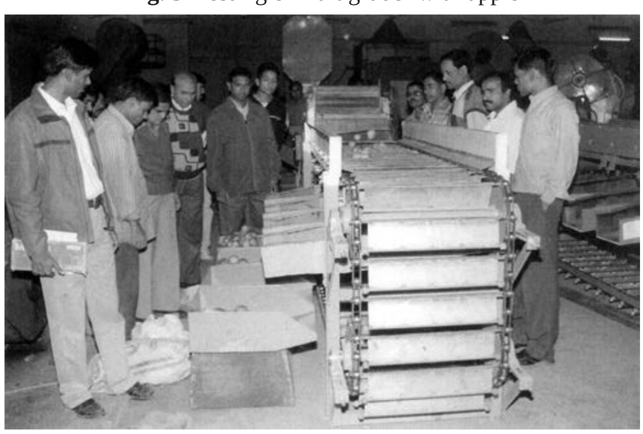


Fig. 3 Testing of fruit grader with apple



Feed Table

A rectangular trough of 1,500 mm × 1,200 mm with sidewalls 200 mm high was made with 1.5 mm thick stainless steel sheet. The trough was sized to hold a maximum of 200 kg of fruit at a time. The rectangular trough was mounted on the MS angle iron frame at an angle of 4º horizontal inclination to facilitate the movement or rolling of the fruits to the feed conveyor by gravity. A stainless steel trapezoidal section that acted as a bridge between feed table and feed conveyor was hinged to a rectangular trough. An adjustable gate of *450 mm × 200 mm* was provided to control the feeding rate. The bags/crates containing the fruit were emptied into the rectangular trough. An operator standing between the feed conveyor and feed table could regulate the feeding of fruit and sort out the damaged/undesirable fruits by visual inspection.

Testing of the Fruit Grader

Testing of the fruit grader was done with sweet lemon, orange, sapota and apple fruits (**Fig. 3**). Care was taken to present all the sizes of fruits for testing. Fruits were fed to the grading unit uniformly by the feed conveyor. About 500 kg of each fruit were used for testing. The fruits were graded into four grades. The flap spacings for Grade I, Grade II, Grade III and Grade IV were adjusted to 55, 65, 75 and 90 mm, respectively, for sweet lemon, orange and apple with the help of the track height adjustment mechanism. The flap spacing of 90 mm was maintained at the last section of the grader to ensure that all the fruits passed through the flap spacing and fell into a collection chute. The flap spacings for Grade I, Grade II, Grade III and Grade IV were adjusted to 35, 45, 55 and 65 mm for sapota fruit. In case of sapota the flap spacing of 65 mm was maintained at the last section to ensure the grading of all the fruits. The above flap spacings were decided on the basis of physical dimensions of fruits. Graded fruits were collected in trays from different chutes. The random samples of 50 fruits were drawn from each grade. The physical dimensions of the individual fruit like major ‘a’, intermediate ‘b’ and minor ‘c’ were measured with a vernier Calliper and recorded. The average geometrical mean diameter (GMD) was calculated using the following formula.

$$GMD = (abc)^{1/3}$$

Determination of Separation Efficiency

From the GMD values all fruits which were not included (undesirable in that particular grade) in a particular size category, whether oversize or undersize, were considered as misclassified fruits (von Beckmann and Bulley, 1978). The number of the misclassified fruits were calculated from the geometrical mean diameter data. The above procedure was replicated, three times and average separation efficiency of a particular grade was calculated using the following formula:

$$E_s = \frac{N_t - N_u - N_o}{N_t} \times 100$$

where,

E_s = Separation efficiency of a particular grade, %

N_t = Total number of sample of a particular grade

N_u = Total number of undersize in that sample

N_o = Total number of the oversize in that sample

The overall grading efficiency was calculated by the following formula:

$$E_s = \frac{N_{to} - N_{tu}}{N_{to}} \times 100$$

where,

E_s = overall separation efficiency of the fruit grader, %

N_{to} = Total number of the sample of all grade fruits

N_{tm} = Total number of the misclassified fruits in all the samples

Calculation of Fruit Damage

The skin damage, cutting damage and bruising damage were defined and calculated as follows:

Skinning damage was defined as the percentage damage caused to the fruits by the action of grader on the basis of the percent skin of the fruits removed. It was calculated as follows:

$$D_s = \frac{N_s}{N} \times 100$$

where,

D_s = Skin damage, %

N_s = Number of fruits in a sample

N = Total number of the fruits in a sample

Cutting damage was defined as the percentage damage caused to the fruits due to the cut injuries resulting from the action of the grader. It was calculated as follows:

$$D_c = \frac{N_c}{N} \times 100$$

where,

D_c = Cutting damage, %

N_c = Number of cut fruits in a sample

N = Total number of the fruits in a sample

Bruising damage was defined as the percentage damage caused to the fruits as a results of the bruising sustained by the fruits due to the operation of the grader. Bruising essentially implies the damage or rupture of the fruit tissues without breaking the skin. A bruised fruit develops a dark spot at the place of bruising after a few days. It was calculated as follows:

$$D_b = \frac{N_b}{N} \times 100$$

where,

D_c = Bruising damage, %

N_c = Number of bruised fruits in a sample

N = Total number of the fruits in a sample

Results and Discussion

The average geometrical mean diameter of fruit samples collected in four grades are presented in **Table 1**. The average geometrical mean diameter of sweet lemon, orange, apple and sapota discharged from the collecting chutes of Grade I, Grade II, Grade III and Grade IV were 51.51, 58.35, 68.06 and 76.66 mm; 51.44, 62.26, 69.00 and 77.03 mm; 52.44, 63.55, 68.29 and 75.43; and 33.28, 42.64, 51.00 and 58.23, respectively. The average geometrical mean diameter of fruit discharged to a particular grade chute was less than the adjusted flap spacing for all the fruits. The number of misclassified fruits, separation efficiency for different grades and overall separation efficiency of the machine is presented in **Table 2**. For sweet lemon, the maximum number of misclassified fruits was 12 (8 undersize and 4 oversize) in all grades. The separation efficiency of a particular grade sweet of lemon ranged from 92 % (Grade II) to 96 % (Grade IV). The overall separation efficiency of sweet lemon was 94 %. For oranges, the maximum number of misclassified fruits was 5 in Grade II (3 undersize and 2 oversize) and 14 in all grades. The separation efficiency of particular grades for oranges ranged from 90 % (Grade II) to 96 % (Grade IV). The overall separation efficiency of oranges was 93 %. For apples the maximum number of misclassified fruits was 18 (9 under size and 9 over size). The over all separation efficiency of apple was 91 %. For sapota the maximum number of misclassified fruits was 14 (7 under size and 7 over size). The separation efficiency of a particular grade ranged from 92 % in Grade II to 96 % in Grade III. The overall separation efficiency of sapota was 93 %. The overall separation efficiency of sweet lemon, orange and sapota was higher than that of the apple due to the higher sphericity of fruits. The capacity of the grader varied from 3.80-4.00 t/h at a grading conveyor speed of 6 m/minute. There was no cutting damage and bruising damage to the fruits except only 2-4 % of skin damage while grading. The cost of operation of the grader was Rs. 800 per tonne.

Table 1 Average geometrical mean diameters of graded sweet lemon, orange and apple in different grades

Fruits	Geometrical mean diameter, mm			
	Grade I (55)*	Grade II (65)	Grade III (75)	Grade IV (90)
Sweet lemon	51.51	58.35	68.06	76.66
Orange	51.44	62.26	69.00	77.03
Apple	52.44	63.55	68.29	75.43
Sapota	Geometrical mean diameter, mm			
	Grade I (35)*	Grade II (45)	Grade III (55)	Grade IV (65)
	33.28	42.64	51.00	58.23

* Numerical value in parenthesis is spacing between the flaps in mm

Table 2 Performance data of the fruit grader

Size category	No. of fruits in category	No. of misclassified fruits		Separation efficiency of particular grade, %	Overall separation efficiency, %	Skinning damage, %	Cutting damage, %	Bruising damage, %
		Under size	Over size					
Sweet lemon								
Grade I	50	---	3	94.00	94.00	0.00	0.00	0.00
Grade II	50	3	1	92.00				
Grade III	50	3	---	94.00				
Grade IV	50	2	---	96.00				
Orange								
Grade I	50	---	4	92.00	93.00	0.00	0.00	0.00
Grade II	50	3	2	90.00				
Grade III	50	3	---	94.00				
Grade IV	50	2	---	96.00				
Apple								
Grade I	50	---	4	92.00	91.00	2.00	0.00	0.00
Grade II	50	---	5	90.00				
Grade III	50	5	---	90.00				
Grade IV	50	4	---	92.00				
Sapota								
Grade I	50	---	3	94.00	93.00	4.00	0.00	0.00
Grade II	50	---	4	92.00				
Grade III	50	4	---	92.00				
Grade IV	50	3	---	94.00				

Economic Perspective of Fruit Grading

The overall cost-economics was calculated considering cost, capacity and time of operation to ascertain the economic feasibility in fruit grading. The details of the procedure adopted were as follows (Mangaraj and Singh, 2006):

Working Capital required for 1 month = (a + b + c + d) = Rs. 584,763

Land and building / shed cost − Rs. 50, 000

Fixed capital investment = (Land + building) + Machinery cost + Working capital = Rs. 832,763

Fixed Cost Per Year

i) *Interest/yr = 75 % of the fixed capital investment × 0.14 + 25 % of the fixed capital Investment × 0.09 = 103,882*

ii) *Depreciation/yr = (Total cost of the machinery − Salvage value) / Life = 16,200*

iii) *Insurance/yr = Cost of the machine × 1.5 % = 2,700*

Total fixed cost per year = (i + ii + iii) = Rs. 122,782

Total variable cost per year = (a + b + c + d) per year = Rs. 1,754,289

Total cost of operation per year = Total fixed cost per year + Total variable cost per year = Rs. 1,877,071

Quantity of fruits graded per year = considering 98 kg of graded fruits obtained from 100 kg raw fruits

Cost of grading (Rs./kg) = Total cost of operation per year (Rs./year)/quantity of fruit graded per year (kg/year) = 1,877,071/ (2,400,000 × 0.98)
= 1,877,071 / 2,352,000
= Rs. 0.80 per kg
= Rs. 800 per tonne

Economic Indicators of Fruit Grading

The details of the cost-economics of fruit grading were calculated using the above mentioned format. The selling price of the graded fruit was fixed considering 20 % profit as compared to the cost of grading fruit and the economic tools and calculated as follows (Erickkasner, 1979):

Break Even Point = Fixed cost per year (Rs/year) / Selling price per unit (Rs/unit) − Variable cost per unit (Rs/unit) = 122,782 / (1 − 0.74) = 122,782 / 0.26 = 472,238 kg = 472.195 tonnes

Assumptions

Working days in a year	8h/day (3 months in a year)
Interest rate / year (if known)	14%
Rented (room/shed/machinery, if assumed)	---
Depreciation rate	10% (life of the machine 10 year)
Any other	
Marginal Money	25%

Machinery/ Equipment

Machinery/ Equipment	No. of Units	Cost per unit	Capacity	Per day processing of fruits, kg	Expected life of machine
Fruit grader	1	180,000	4,000 kg/h	32,000	10

Installation cost @ 10% = Rs. 18,000
Total cost of machine and installation = Rs. 19,800.00

Variable cost a) Raw material

Raw material	@ rate/ unit, Rs/Kg	Quantity/ day, Kg	Quantity/ yr., Kg	Total cost in Rs.	
				/month	/year
Fruits	---	---	---	---	---

Considering that the fruit grower has owned the fruit grader, then the cost of raw material i.e. cost of fruits is nil.

Variable cost b) Employment

Labors*	Quantity	Rate @ month	Total cost/year
Skilled labor	1	2,875	8,625
Un Skilled labor	6	2,400	43,200
Total cost		17,275	51,825

Variable cost c) Utilities

Power (Electricity)	@ Kwh/day (consumption)	@	Total Cost in Rs.	
			/month	/year
Motor/ Engine	17.90	4	1,790	5,370
Light (tube/bulb)	0.42	4	42	126
Fan	0.55	4	56	168
Total cost			1,888	5,664

Variable cost d) Other Expenditures (As per requirement)

Name	Quantity required /day	@ Rate/ unit	Monthly expenditure	Total Cost/yr
Packaging material	1,600 box	Rs. 10/box	400,000	1,200,000
Repair and maintenance	6 % of the machinery cost		3,600	10,800
Transportation cost	Rs. 6,400 /day	Rs. 0.20 /kg	160,000	480,000
Miscellaneous			2,000	6,000
Total cost			565,600	1,696,800

* One box of fruits = 20 kg

Return on Investment = Fixed cost per year (Rs/year) / Selling price per unit (Rs/unit) − Variable cost per unit (Rs/unit) = 122,782 / (1 − 0.74) = 122,782 / 0.26 = 472,238 kg = 472.195 tonnes

Return on Investment = Net Profit per year (Rs/year) / Fixed Capital Investment (Rs/year) × 100

Total revenue = Total final product × Selling Price of the product

Total cost of operation = Fixed cost + Variable cost

Net Profit = Total Revenue − Total cost of operation

R. O. I. for the fruit grading = [Net profit from all the machinaries / Fixed capital investment] × 100 = (474,929 / 814,763) × 100 = 58 %

Pay Back Period = [Fixed Capital Investment (Rs/year) − Working Capital (Rs/period)] / Net Profit (Rs/year) = 230,000 / 474,929 = 0.48 Year

Conclusions

A stepwise expanding pitch fruit grader based on the principle of changing the flap spacing along the length of movement of fruits was designed and developed. The fruit grader was tested for grading sweet lemon, orange, sapota and apple fruits into four grades. The overall separation efficiency of the fruit grader was 91-94 % for the fruits. There was no damage to the fruits while grading. Considering the fruit grader was owned by the apple fruit grower and duration of operation was 8/h per day for 3 months in a year, the cost of grading was estimated to be Rs. 800 per tonne. The break even point, return on investment and payback period was estimated to be 472,195 kg, 58 % and 0.48 year, respectively, taking into account the procurement of fruit for grading and the fruit grower is grading the fruit.

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Technological Impact on Energy Requirements for Wheat Cultivation in North India

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Abstract

India has emerged as the second largest producer of wheat in the world, close on the heels of China. Development and adoption of improved farm technologies has helped boost yields, provide resistance to important pests and diseases and other undesirable traits, spread of irrigation, storage, transport, processing and marketing, coupled with congenial price policies, all helping enhance the production and productivity of wheat. The transition in technology and agricultural development has brought in a shift in the choice of energy resources under use. The use of non-renewable energy sources has been increasing in the process. Adoption of an energy-efficient cultivation system would help in energy conservation and better resource allocation.

For the wheat crop, data were collected from 780 irrigated farms spread over Tarai and Bhabar regions of Uttar Pradesh and five agro-climatic zones of the Punjab State. All the farms had the combination of tractor power and diesel engine and electric motor pumps as stationary power sources. The energy consumption patterns of these farms were studied and linear programming technique applied to determine optimal energy resource allocation for maximum yield obtainable under business-as-usual and improved cultivation practices. The results indicated that 16,635 MJ/ha of energy is presently consumed for an average yield of 3,646 kg/ha. Fertiliser provided 41 percent of the energy, followed by diesel, electricity, seed, farmyard manure, human, machinery and agro-chemicals. Based on the performance of the farms, optimal energy resource allocation suggests that 38.50 percent additional yield can be obtained without any major change in energy use pattern. Energy saving of 8.30 percent is also feasible with optimal energy resource allocations. Since the optimisation is based on actual performance of the sample size, it appears that the energy resource management by the majority of farmers has been sub-optimal.

The results also suggest that by adopting improved cultivation practices and recommended seed and fertiliser application rates, the yield level can increase to 5,792 kg/ha with an investment of 17,230 MJ/ha of total energy. The optimized energy use requires 17.40 percent higher fertiliser, and 60.72 percent higher machinery energy for timely sowing of the crop with improved sowing implements and timely completion of time bound operations. Energy productivity in the process would increase to 0.336 kg/MJ from 0.219 kg/MJ presently being obtained by the farmers. The estimate of optimized energy resource allocation (using improved practices) required for attaining the potential yield level observed in research farms indicate that investment of 22,378 MJ/ha would be required for a yield level of 6,000 kg/ha. When compared with optimal energy resource allocation for business-as-usual approach, fertiliser use would increase by about 48 percent for the increase in yield by 19 percent. Diesel energy use would increase by 54 percent. As a consequence, electricity and human energy use would reduce by about 10 and 19 percent, respectively. The total energy consumption (using improved practices) increases with increase in productivity. The share of indirect energy increases faster than direct energy due to fertiliser consumption pattern. Energy productivity would improve to 0.426 kg/MJ, the rate of improvement being higher till yield level of 2,500 kg/ha. The total direct energy consumption in business-as-usual practice is, however, more than in the improved

practice, the difference being more pronounced at lower productivity levels. The pattern is governed by the consumption pattern of direct commercial energy. The potential of saving of human energy and electricity in the process would provide a better energy management option for cultivation of the crop.

Introduction

Indian agriculture has transformed from food shortages to self-reliance and surplus owing to technological breakthrough as well as policy and programmatic initiatives of the government. Agriculture and allied sectors contribute 24.2 percent of country's gross domestic product and 15.2 percent of export. The food grain production has reached to 212.02 million tones in 2001-02 from merely 50.82 million tones in 1950-51. Wheat constitutes about 35 percent of the total food-grain production. The area under food grains increased by 26 percent while production increased by 315 percent, signifying a quantum jump in productivity. The area under irrigation is 86 percent in wheat. These achievements are attributed to the concerted planned strategic policy interventions, programmatic approach and response of our farming community to become active agents of development designs.

Energy has an indispensable input for economic development. Agricultural experts all over the world have marshaled ample evidence to support that energy use per hectare has direct bearing on the crop yield. Indian agriculture has witnessed a tremendous transformation since independence particularly due to the 'Green Revolution' of the sixties. As a consequence, the food production has increased about four fold, leading the country towards self-reliance and food security. Energy has played a key role in this transformation process. Notwithstanding the achievements in the agricultural sector, the fact is that much remains to be achieved in the face of mounting demand for agricultural commodities with the increasing population, rising per capita income and growing awareness about health and nutrition. In a land scare agrarian economy like India, a large volume of additional production has to be achieved by energy intensification and judicious management of the energy system. The energy intensification led growth strategy for augmenting agricultural production could be viewed as a 'double edged weapon' that on one count cuts the bottlenecks for higher production in the short run, while on the other it prunes the stock of natural and non-renewable resources in the long run. This 'double edged' nature of energy intensification has given rise to umpteen apprehensions about imminent energy crisis and environmental hazards, raising concerns about sustainability of the agricultural production system.

Agriculture in India has gone into more or less total transformation from organic to inorganic agriculture. Increasing use of commercial energy has made agriculture move with a fast stride. Energy, as an input, is attaining higher demands with the growth of agricultural production that is a priority goal in agriculture to sustain ever-growing population.

This paper attempts to assess the present energy use pattern in irrigated wheat cultivation in tractor farming systems in north India and compares their efficacy at different levels of productivity under business-as-usual and improved cultivation practices.

Material and Methods

A survey was conducted during 1997-2002 by the G. B. Pant University of Agriculture and Technology (GBPUAT) and Punjab Agricultural University (PAU) co-operating centre of the All India Coordinated Research Project (AICRP) on "Energy Requirement in Agricultural sector" for energy audit on crop production activity considering whole village approach.

For irrigated wheat crop, data were collected from 780 farms from Tarai and Bhabar regions of Uttar Pradesh and 5 agro-climatic zones of the Punjab State namely Zone 1 (district Nawansahar), Zone 2 (district Hoshiarpur), Zone 3 (district Ludhiana and Kapurthala), Zone 4 (district Sangrur) and Zone 5 (district Bhatinda). All the farms had the combination of tractor power and diesel engine and electric motor pump as a stationary power source.

Necessary statistical techniques were applied for identification of outlier points, which were deleted for further analysis. A data point was considered as outlier if standardized residual value was beyond the +/− 3 limits.

Six outlier data points so detected were deleted from the data set. Thus, data pertaining to only 774 farms were finally considered for further analysis. The physical values of different energy inputs used by the individual farmers were converted to mega joule (MJ) units by using the energy co-efficient developed under the Project (**Table 1**). Energy consumed in each farm operation by each farmer was also calculated.

Energy Optimising Model

Since the production model was found to be linear in character, linear programming technique was used to determine the optimal energy inputs for maximum yield obtainable from the given data set of energy inputs used by the farmers and corresponding yields obtained.

Linear programming technique has been applied for crop production system analysis by different researchers. Major areas of application include allocation of labour employment [7, 12], land allocation among competitive crops [4], cultivation practice optimisation [2,5], machinery use planning [10-15], land farm planning for minimum soil movement [13] and governmental resource allocation for agriculture conservation programmes [9]. The technique has also been used in optimisation of either farm return or energy use by different researchers [1, 3, 6, 8, 11, 14] by considering energy consumption or other relevant parameters.

In the present study, the objective function considers the data of energy usage and productivity of each farmer of the data set as a separate activity.

Let X_i denote the area allocated according to the energy usage of activity *i* in hectares and Y_i denote the yield (kg/ha) from the activity *i*. Then the objective function is:

$$maximize\ yield = \sum_{i=1}^{n} Y_i X_i$$

subject to constraints:

$$A_1 \leq \sum_{i=1}^{n} h_i X_i \leq A_2 \quad \text{..................} (1)$$

where,

h_i = human energy level for activity *i*, MJ/ha

A_1 = lower bound on human energy available per activity, MJ/ha

A_2 = upper bound on human energy available per activity, MJ/ha

$$A_{1n} \leq \sum_{i=1}^{n} an_i X_i \leq A_{2n} \quad \text{.............} (2)$$

where

an_i = animal energy level for activity *i*, MJ/ha

A_{1n} = lower bound on animal energy available per activity, MJ/ha

A_{2n} = upper bound on animal energy available per activity, MJ/ha

$$D_1 \leq \sum_{i=1}^{n} d_i X_i \leq D_2 \quad \text{..................} (3)$$

where,

d_i = diesel energy level for activity *i*, MJ/ha

D_1 = lower bound on diesel energy available per activity, MJ/ha

D_2 = upper bound on diesel energy available per activity, MJ/ha

$$E_1 \leq \sum_{i=1}^{n} e_i X_i \leq E_2 \quad \text{..................} (4)$$

where,

e_i = electric energy level for activity *i*, MJ/ha

E_1 = lower bound on electric energy available per activity, MJ/ha

E_2 = upper bound on electric energy available per activity, MJ/ha

$$S_1 \leq \sum_{i=1}^{n} s_i X_i \leq S_2 \quad \text{...................} (5)$$

where,

s_i = seed energy level for activity *i*, MJ/ha

S_1 = lower bound on seed energy available per activity, MJ/ha

S_2 = upper bound on seed energy available per activity, MJ/ha

$$F_1 \leq \sum_{i=1}^{n} f_i X_i \leq F_2 \quad \text{..................} (6)$$

where,

f_i = fertiliser energy level for activity *i*, MJ/ha

F_1 = lower bound on fertilizer energy available per activity, MJ/ha

F_2 = upper bound on fertilizer energy available per activity, MJ/ha

$$M_1 \leq \sum_{i=1}^{n} m_i X_i \leq M_2 \quad \text{...............} (7)$$

where,

m_i = machine energy level for activity, MJ/ha

M_1 = lower bound on machine energy available per activity, MJ/ha

M_2 = upper bound on machine energy available per activity, MJ/ha

$$C_1 \leq \sum_{i=1}^{n} c_i X_i \leq C_2 \quad \text{..................} (8)$$

where,

c_i = agro-chemical energy level for activity , MJ/ha

C_1 = lower bound on agro-chemical energy available per activity, MJ/ha

C_2 = upper bound on agro-chemical energy available per activity,

Table 1 Equivalent coefficient for various sources of energy

Energy source	Units	Equivalent energy, MJ
Human	Man-hour	1.96 1 Adult woman = 0.8 Adult man 1 Child = 0.5 Adult man
Animal	Pair-hour	10.10 (Body weight 350-450 kg)
Diesel	litre	56.31
Electric	KWh	11.93
Seed	kg	14.7
FYM	kg	0.3
Fertiliser		
Nitrogen	kg	60.6
P_2o_5	kg	11.1
K_2o	kg	6.7
Agro-chemicals		
Superior chemicals	kg	120 Chemicals requiring dilution at the time of application
Inferior chemicals	kg	10.0 Chemicals not requiring dilution at the time of application
Machinery		
Electric motor	kg	64.80
Prime movers other than electric motors	kg	68.40
Farm machinery excluding self propelled machines	kg	62.70

MJ/ha

$$T_1 \le \sum_{i=1}^{n} t_i X_i \le T_2 \quad \text{.....................(9)}$$

where,

t_i = total energy consumed by activity in MJ/ha

T_1 = lower bound on total energy available per activity in MJ/ha, MJ/ha

T_2 = upper bound on total energy available per activity in MJ/ha, MJ/ha

The upper bound on total energy should not exceed the sum of upper bounds on all other constraints. Similarly, the lower bound on total energy should not be less than the sum of lower bounds on all other energy sources. For the present analysis, the lower bound of all energy sources was taken as zero.

When $X_1 = 1, X_2 = X_3 = ...X_n = 0$, we get yield ($Y_1$) obtained by the farmer X_1 and the solution for the same as the energies used by that activity (farmer). Hence, the objective function has a logical interpretation.

One more constraint was also defined as the following:

$$\sum_{i=1}^{n} X_i = 1$$

This ensures that the maximization of yield per hectare basis gives equal weight to each of the activities.

The number of decision variables (or activities) included in the solution will be less than or equal to the number of constraints in the model.

Once the solution for X_i's, say x_i''s is obtained, the value of objective function (i.e. the value of the maximum yield) and usage of various energy sources are obtained using the expressions

$$yield = \sum_{i=1}^{n} Y_i X_i^*$$

$$human\ energy = \sum_{i=1}^{n} h_i X_i^*$$

$$animal\ energy = \sum_{i=1}^{n} an_i X_i^*$$

$$diesel\ energy = \sum_{i=1}^{n} d_i X_i^*$$

$$electrical\ energy = \sum_{i=1}^{n} e_i X_i^*$$

$$seed\ energy = \sum_{i=1}^{n} s_i X_i^*$$

$$fertilizer\ energy = \sum_{i=1}^{n} f_i X_i^*$$

$$machine\ energy = \sum_{i=1}^{n} m_i X_i^*$$

$$chemical\ energy = \sum_{i=1}^{n} c_i X_i^*$$

$$total\ energy = \sum_{i=1}^{n} t_i X_i^*$$

Since $t_i = h_i + an + d_i + e_i + f_i + s_i + m_i + c_i$, the sum of the energy usage from different sources shall be equal to the total energy usage.

The values of the decision variables were similarly used for calculating the energy used in each operation.

Results and Discussion

The average yield of the farms under study was 3,646 kg/ha; more than the national average. The average, maximum and minimum yields and source-wise energy consumptions of the farms are given in **Table 2**.

The farmers in the study area used energy from eight different sources, viz; human, diesel, electricity, seed, farmyard manure, fertiliser, agro-chemical and machinery. Among the energy sources, fertiliser was the main energy source contributing about 41 percent of total energy consumed. The share of other energy sources were 26.79, 11.73, 10.26, 3.83, 3.03, 2.80 and 0.85 percent for diesel, electricity, seed, farmyard manure, human, machinery and agro-chemicals, respectively. Use of electricity has been only for the irrigation and threshing of the crop.

Optimum Yield and Energy Requirements Under business-as-usual cultivation practices

The average quantities of different energy sources used by the farmers represent the energy consumption pattern for business-as-usual cultivation practices adopted by the tractor farms.

Fig. 1 gives a graphical presenta-

Table 2 Source wise energy use pattern for soybean production under existing farm practices+

	Yield (kg/ha)	HUM	DSL	ELE	SEEDS	FYM	FER	CHE	MACH	TE	Energy productivity (kg/MJ)
AV	3,646	504	4,457	1,952	1,707	637	6,771	141	466	16,635	0.219
MAX	5,930	1,481	12,549	6,283	3,632	1,483	12,195	850	1,356	24,552	0.377
MIN	1,153	72	1,770	0	778	0	1,705	0	150	7,346	0.106

+MJ/ha, except as noted

Nomenclature: Acronyms used in tables

AV = average, CHE = agro-chemical, DSL = diesel, ELE = electric, FER = fertiliser, FYM = farmyard manure, HAR = harvesting, HUM = human, MACH = machinery, MAX = maximum, MIN = minimum, SOW = sowing, SPR = spraying, TE = total energy, THR = threshing, TILL = tillage, TRAN = transportation

tion of the pattern of total energy consumed in the farms at different levels of productivity. The actual energy use patterns indicate that the farms belonging to the peak regime of the regression model had obtained average yield of 5,325 kg/ha by investing an average total energy of 19,778 MJ/ha. Farmers falling in the two adjacent tapering sides of the regression curve had lower average yields. Farms using higher total energy appear to be not efficiently managed as even with use of higher quantity of fertiliser, and higher energy consumed for tillage and irrigation could have lower yield than group of farms belonging to the peak regime of the regression model.

With the average quantities of different energy sources used by the farmers representing the energy resource use patterns for business-as-usual cultivation practices as upper bounds, optimisation of energy resource uses indicated that a maximum yield of 5,049 kg/ha can be obtained, signifying that 38.50 percent of additional yield than the average yield can be obtained by using same quantity of energy inputs (**Table 3**). Energy saving of 8.30 percent is also feasible with optimal energy resource allocations. Since the optimisation is done based on actual performance of the sample size, it appears that the energy resource management by the majority of farmers has been sub-optimal. The optimized resource allocation can improve the energy productivity from 0.219 to 0.331 kg/MJ.

The optimum energy resource allocations providing higher crop yields would be achievable through restructuring the input uses and operational energy uses. Among the major field operations in tractor farms, the sowing operation would require 12.64 percent additional energy for sowing the seed with seed-cum-fertilizer drill for proper placement of the seed into the soil while the threshing operation would require 90 percent higher energy to thresh the additional crop yield. Energy saving would be possible in tillage by 2.27 percent and in irrigation by 7.63 percent through use of energy efficient machines and implements. The present policy of subsidy/free supply of electricity to agriculture tends to lead to its inefficient use in continuous operation like irrigation. Although the total fertiliser energy use would be same, the combination would change with increased use of phosphoric fertiliser by 31 percent (from 45 to 59 kg/ha) and reduced use of nitrogenous fertiliser by 5 percent (from 109 to 104 kg/ha). The consumption of seed can be reduced by 5 percent (from 116 to 111 kg/ha) by using the improved sowing devices. Thus, energy use efficiency can be improved with reduced seed rate, better fertiliser combination and judicious water application and use of energy efficient tillage implements.

Optimal Yield with Use of Improved Package of Practices

Improved package of practices using improved implements have been recommended by the Cooperating Centres (*i.e.* GBPUAT, Pantnagar and PAU, Ludhiana) of AICRP on Farm Implements and Machinery for cultivation of the crop in the study area. The recommended package (**Table 4**) was considered for as-

Table 3 Maximum yield and optimal energy consumption under existing farm practice+

Yield (kg/ha)	HUM	DSL	ELE	SEEDS	FYM	FER	CHE	MACH	TE	Energy productivity, kg/MJ
5,049	504	4,457	1,367	1,629	0	6,771	60	466	15,254	0.331

+MJ/ha, except as noted

Fig. 1 Energy use pattern for different levels of wheat productivity by faumers

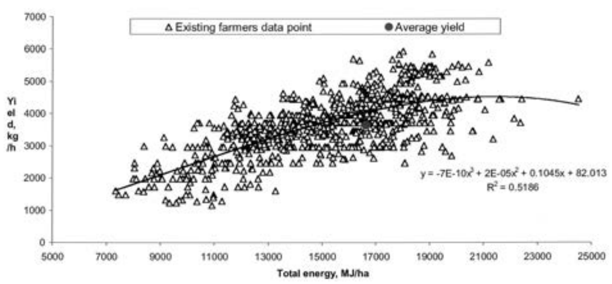


Table 4 Improved package of practice for wheat cultivation

Operation	Practice
Seedbed Preparation	*Tractor drawn plough × 1 + Tractor drawn harrow × 2 + plank × 1 or Tractor drawn Rotavator × 2 + plank × 1*
Sowing	Tractor drawn fertilizer - seed drill or Or zero tillage fertiliser- seed drill
Irrigation	*Electric motor / Diesel engine operated tube well × 4 (50 : 50)*
Fertilizer application	*Manual × 2*
Agro-chemical Spraying	Knapsack or tractor drawn sprayer
Harvesting	Partly by manual and partly by combine harvester
Threshing	Power thresher
Transport	Tractor-trailers

sessment of uses of various energy resources.

The source-wise energy consumption for adopting the improved package of practices were evaluated and used as upper bounds. The optimum use of different energy resources for the improved package of practices obtained through linear programming analysis is given in **Table 5**.

The results (**Table 5**) indicate that with a 3.58 percent increase in energy consumption from 16635 MJ/ha to 17,230 MJ/ha, the farmers can obtain 58.85 percent additional crop yield with improved cultivation practices. The optimized energy use requires 17.40 percent higher fertiliser, and 60.72 percent higher machinery energy for timely sowing of the crop with improved sowing implements and timely completion of time bound operations.

Energy Use for Potential Yield

The maximum potential yield obtainable in the study area has been determined through experiments and On Farm Trials (OFT) conducted under AICRP on Cropping Systems Research, GBPUAT, Pantnagar and PAU, Ludhiana. Results indicate potential yield ranging between 5,300 to 6,000 kg/ha at research stations located in the study areas, and higher than that obtained in the farms under study. Six simulated data sets were generated for fixed yield levels, using corresponding seed and fertiliser application rates and improved operational package of practices as indicated above (**Table 6**). Slight variations in energy allocations were built in for better linear programming responses.

The simulated data set was included with the farmer data set to optimize energy resource allocation for maximum potential yield of the crop. The resource allocation obtained through application of linear programming is indicated in **Table 7**.

It may be seen that a maximum yield of 6,000 kg/ha is feasible to be obtained with an investment of 22,378 MJ/ha of energy.

As compared with optimized existing practice, animal energy use would increase by 83.4 percent, signifying better use of available renewable energy resource for tractive purposes. As a consequence, diesel use would reduce by 32.1 percent. The recommended fertiliser use for 48.9 percent higher yield would entail use of 98.7 percent additional fertiliser energy. Electricity consumption increase is for threshing additional crop harvested. Total energy use would increase by 28.9 percent. **Fig. 2** presents the total energy use regression models discussed above. With optimal energy uses, the yield levels with improved package of practices are higher for the improved package of practices as compared with the business-as-usual approach.

Direct Energy Use

Use patterns of direct energy resources in production agriculture are of special interest for planning purpose. Direct energy resources are used in the farms for execution of different farm operations. The trends of uses of direct energy resources have been dynamic in the country with major shift to

Table 5 Maximum yield and optimal energy consumption under improved cultivation practices+

Yield (kg/ha)	HUM	DSL	ELE	SEEDS	FYM	FER	CHE	MACH	TE	Energy productivity, kg/MJ
5,792	409	4,231	1,231	1,635	637	8,041	297	749	17,230	0.336

+MJ/ha, except as noted

Table 6 Simulated data to represent maximum potential yield and source-wise energy use+

Yield (kg/ha)	HUM	DSL	ELE	SEEDS	FER	CHE	MACH	TE	Energy produc-tivity (kg/MJ)
6,000	207	3,770	2,111	1,635	8,729	297	749	17,498	0.343
6,000	759	3,704	2,815	1,635	7,972	297	722	17,934	0.335
6,000	707	5,625	2,111	1,562	8,041	297	548	18,891	0.318
6,000	197	4,010	3,519	1,562	8,041	297	724	18,350	0.327
6,000	180	1,139	2,463	1,635	8,041	297	340	14,095	0.426
6,000	594	2,311	2,463	1,635	8,041	297	414	15,755	0.381

+MJ/ha, except as noted

Table 7 Maximum potential yield and optimum energy resource allocation+

Yield (kg/ha)	HUM	DSL	ELE	SEEDS	FYM	FER	CHE	MACH	TE	Energy productivity, kg/MJ
6,000	1,481	6,512	6,283	3,632	282	9,986	850	1,350	22,378	0.426

+MJ/ha, except as noted

commercial sources as electricity and diesel. With large and continuing investments by the farmers on power sources using electricity and diesel, it has become imperative to ensure timely and adequate supplies of these resources so that investments made are fully exploited. Proper uses of the energy resources are equally important for reducing wasteful uses of the scarce commodities.

Figs. 3a, 3b and **3c** indicate the patterns of animate (human and animal), direct commercial (diesel, electricity) energy and total direct energy consumptions, respectively, at different yield levels of productivity when cultivated using business-as-usual practices and with optimized energy resource allocations using improved practices. For improved cultivation practice, human energy consumption averages 504 MJ/ha.

The direct commercial energy use consequently is estimated to be lower in improved cultivation practice as compared with the business-as-usual practice (**Fig. 3b**). With use of improved cultivation practices, the consumption rate would be lower, the difference being higher at yield levels between 4,000-5,500 kg/ha. Consequently, the total direct energy consumption in business-as-usual practice would be more than in the improved practice, the difference being higher at higher productivity levels (**Fig. 3c**). For a yield of 5,000 kg/ha, diesel consumption would decrease by 23.40 percent and electricity consumption would decrease by 36.87 percent. The pattern is governed by the consumption pattern of direct commercial energy, mainly due to increase in diesel consumption.

Fig. 4 represents the energy consumption patterns for improved cultivation practice. Total energy consumption increases with increase in productivity, the share of indirect energy increasing faster than that of direct energy due to nearly 18 percent increased use of fertiliser for productivity increase from 3,646 to 6,000 kg/ha. Energy productivity shows a fast improvement until a yield of about 5,000 kg/ha, and then slows down.

Total direct energy consumption rate increases with increase in productivity, mainly due to increased consumption rate in threshing and transportation. Energy consumption

Fig. 2 Optimum energy use patterns for different levels of wheat productivity

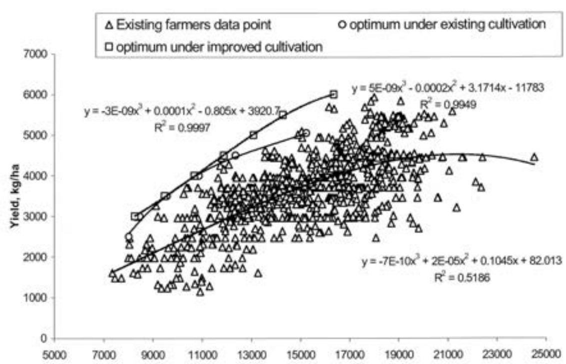


Fig. 3a Companision of human energy use patterns for different levels of wheat productivity under existing and improved cultivation practices

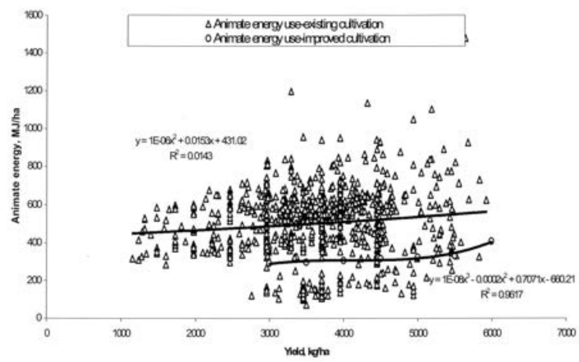


Fig. 3b Comparision of direct commercial energy use patterns at different productivity levels under existing and improved cultivation practices

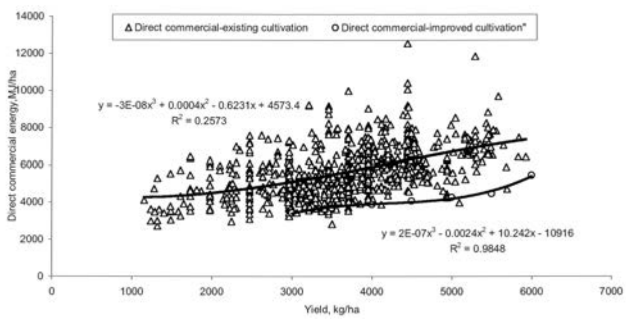
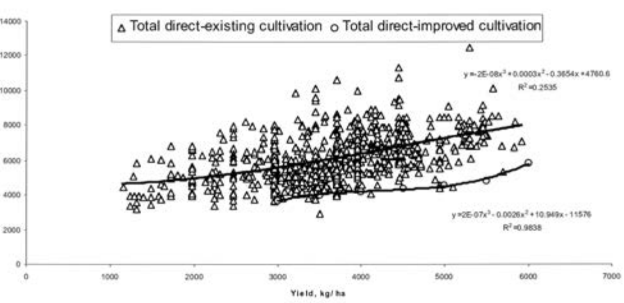


Fig. 3c Comparision of total direct energy use patterns at different productivity levels under existing and improved cultivation practices



in threshing operation increases nearly 1.80 times with increase in productivity from 3,000 to 6,000 kg/ha due to continuous shift to combine use in order to ensure timeliness in operation (**Table 8**).

Conclusions

Wheat has been equally important in stabilizing the food grain production in the country. It occupies about 54 percent of the area under food grains and contributes about 71 percent of the total food grains production of the country during the Rabi season. The transition in technology and agricultural development has brought in a shift in the choice of energy resources under use. The use of non-renewable energy sources has been increasing in the process. Adoption of energy-efficient cultivation system would help in energy conservation and better resource allocation.

Energy audit of 780 tractor farms during 1997-2002 indicates that 16,635 MJ/ha of energy is presently consumed for an average yield of 3646 kg/ha. Fertiliser provided 41 percent of the energy, followed by diesel, electricity, seed, farmyard manure, human, machinery and agro-chemicals. Based on the performance of the farms, optimal energy resource allocation suggests that 38.50 percent additional yield can be obtained without any major change in energy use pattern. Energy saving of 8.30 percent is also feasible with optimal energy resource allocations. Since the optimisation is done based on actual performance of the sample size, it appears that the energy resource management by the majority of farmers has been sub-optimal.

The results also suggest that by adopting improved cultivation practices and recommended seed and fertiliser application rates, the yield level can increase to 5,792 kg/ha with investment of 17, 230 MJ/ha of total energy. The optimized energy use requires 17.40 percent higher fertiliser, and 60.72 percent higher machinery energy for timely sowing of the crop with improved sowing implements and timely completion of time bound operations. Energy productivity in the process would increase to 0.336 kg/MJ from 0.219 kg/MJ presently being obtained by the farmers.

The estimate of optimized energy resource allocation (using improved practices) required for attaining the potential yield level observed in research farms indicate that investment of 22,378 MJ/ha would be required for an yield level of 6000 kg/ha. When compared with optimal energy resource allocation for business-as-usual approach, fertiliser use would increase by about 48 percent for the increase in yield by 19 percent. Diesel energy use would increase by 54 percent. As a consequence, electricity and human energy use would reduce by about 10 and 19 percent respectively. The total energy consumption (using improved practices) increases with increase in productivity, the share of indirect energy increasing faster than direct energy due to fertiliser

Fig. 4 Pattern of energy consumption at different levels of productivity under improved cultivation practices

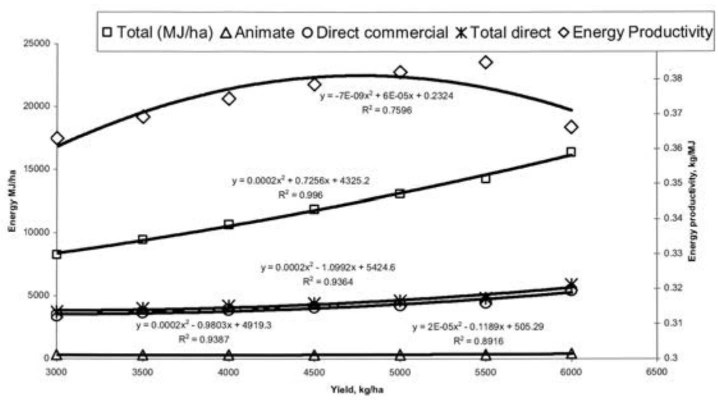


Table 8 Source wise/operation-wise energy use pattern for different levels of productivity with improved cultivation practices+

Yield (kg/ha)	Energy productivity (kg/MJ)	Source-wise direct energy consumption, MJ/ha			Operation-wise energy consumption, MJ/ha					
		HUM	DSL	ELE	TILL	SOW	SPR	HAR	THR	TRAN
6,000	0.366	409	4,231	1,231	0	777	36	626	2,674	125
5,500	0.385	333	3,427	1,047	213	722	30	924	236	116
5,000	0.382	324	3,414	863	425	669	29	785	473	107
4,500	0.378	316	3,401	680	639	616	23	647	710	98
4,000	0.374	306	3,388	496	851	562	17	508	947	89
3,500	0.369	297	3,375	312	1,064	509	11	369	1,184	84
3,000	0.363	292	3,366	60	1,216	458	8	185	1,481	81

+MJ/ha, except as noted

consumption pattern. Energy productivity would improve to 0.426 kg/MJ with the rate of improvement being higher until a yield level of 2,500 kg/ha. The total direct energy consumption in business-as-usual practice is, however, more than in the improved practice, the difference being more pronounced at lower productivity levels. The pattern is governed by the consumption pattern of direct commercial energy. The potential of saving of human energy and electricity in the process would provide better energy management option for cultivation of the crop.

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Grinding Characteristics of Dried Water Chestnut Kernel in Batch Processing

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Abstract

Grinding or size reduction is one of the oldest unit operations and is extensively used in food industry. As far as the process of grinding is concerned, power consumption, specific energy consumption and particle size distribution and mill capacity are main considerations from an engineering point of view. The effect of the speed of the mill and time of grinding on power consumption and average particle diameter of water chestnut in the batch grinding process were studied. Power consumption was measured for a period of time ranging from 120 sec to 360 sec at different speeds of the mill that varied from 800 to 1,200 rpm for batch sizes of 100, 150 and 200 gm. For all the batch sizes, it was observed that, as the speed of the mill increased, there was an increase in power consumption that was significantly higher for the larger batch size. In all the cases initial power consumption was in a higher range and, as time continued, the power requirement gradually reduced to some extent. The relationship between power consumption and time of grinding is a straight line. The size distribution of the water chestnut kernel for different speeds and time of grinding and different batch sizes were obtained by sieve analysis. For a particular batch size and time of grinding, finer particles were produced for higher mill speeds. Taking mill speed and time of grinding constant, showed that, at higher mass size, less fine particles were produced. However, when speed of the mill was increased, finer particles were generated. The Harris model was found best suitable to describe the size distribution in batch grinding process.

Introduction

Water chestnut (Trapa bisinosa Roxburg) commonly known as Singhara, is an annual aquatic warm season crop. Water chestnut belongs to 'trapaceae' family. In India, the two popular species trapa bispinosa and trapa quadrispinosa of water chestnut are widely cultivated. In general, the cultivation of water chestnut is distributed through out the country especially in Punjab, Bihar, Uttar Pradesh Madhya Pradesh, Tamilnadu, Maharastra and in some parts of Uttarakhand. Water chestnuts can be used in a variety of recipes because they have a starchy taste that is fairly neutral. Some people claim that their flavor is similar to a bland nut. Water chestnuts also have a firm and crispy texture, which adds to their appeal as an ingredient in stir-fries, salads, or

Acknowledgement

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any meals where the vegetables to be used must have a crunchy consistency.

Materials and Methods

Commercial grade water chestnut procured from local markets was used as the basic raw material for the present study. The kernels were cleaned and stored in poly bags at room temperature. For the grinding operations a hammer mill (Willey mill) with fixed blades was used in the study. A Ro-tap sieve shaker was used to obtain size distribution of ground material. The sieve shaker was provided with a timer to control the sieving time and operated electrically. A set of 5 standard sieves (1.00, 0.710, 0.500, 0.250 and 0.125 mm) and pan were used for the sieve analysis of ground material.

To study the effect of different operational conditions of a hammer mill on the power requirement and particle size distribution of the ground material, the experiment was planned to observe the grinding behavior of water chestnut kernels. Mill speeds, batch size and time of grinding were considered as independent variables and power consumption and particle size distribution were taken as dependent variables for batch grinding. The full factorial design was used for batch grinding. The experimental plan comprised three independent variables with three levels each. A plan and full design matrix are presented in **Table 1**.

The batch grinding test was performed using a blind screen appropriately fitted to the outlet of the grinding section to stop the mill out flow. At first no load power consumption was recorded by running the hammer mill using a watt meter at every setting of speed of operation of the mill.

Table 1 Experimental plan

Experimental variable	No. of levels	Levels	
		Coded	Uncoded
Batch size(gm)	3	X1	100
		X2	150
		X3	200
Speed of mill, rpm	3	Y1	800
		Y2	1,000
		Y3	1,200
Time of grinding, sec	3	Z1	120
		Z2	240
		Z3	360

Results and Discussion

Power Consumption

The power consumption for batch grinding as affected by mill speed, sieve size and feed rate was observed. Full second order models were fitted for the variation of power consumption with the independent parameters. The relationships obtained were as follows:

$$P = 56.52 - 8.21X - 12.96Y + 5.32Z - 0.25X^2 + 0.03Y^2 + 0.11Z^2 + 2.38XY - 0.46YZ - 0.3XZ \quad (1)$$

The results of analyses of variance (ANOVA) for the second order model were applied. The coefficient of determination, (R^2) of **Eqn. 1**, value of 99.27 % caused this model to be accepted.

Power consumption was measured for a period of time ranging from 120 sec to 360 sec at different speeds of the mill and batch sizes. **Fig. 1** to **Fig. 9** exhibit the characteristic feature of grinding. In **Fig.1** to **Fig. 3**, power consumption was shown for three levels of time of grinding for 100 g batch size. The trends show that, as the speed of the mill increases, there was an increase in power consumption. **Fig. 4** to **Fig. 9** represented same behavior for sample sizes of 150 and 200 g. These graphs show that, for larger batch size, the power requirement was significantly high. The same trend was observed in other operational conditions also. In all the cases, initial power consumption was in higher range and gradu-

Fig. 1 Effect of rpm on power consumption for a 100 g sample and 120 sec of grinding in the batch grinding process

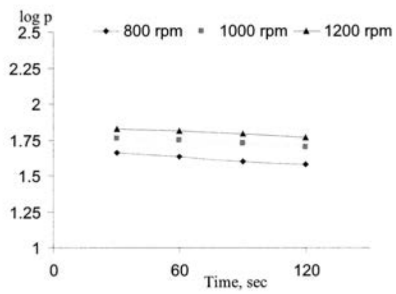


Fig. 2 Effect of rpm on power consumption for a 100 g sample and 240 sec of grinding in the batch grinding process

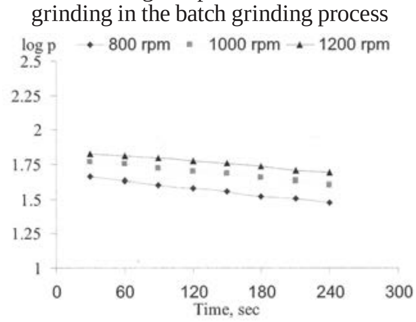
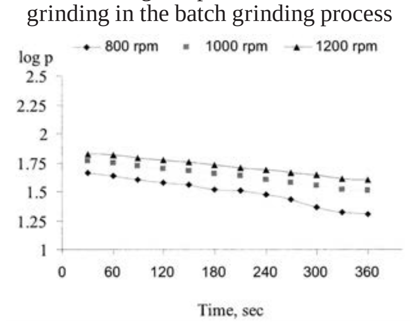


Fig. 3 Effect of rpm on power consumption for a 100 g sample and 360 sec of grinding in the batch grinding process



ally, as time continued, the power requirement reduced to some extent. It may be due to the reason that, initially, to break the whole grain or its broken fractions, large power was required since the grain offers more resistance to breakage. After initial breakage the smaller particles offered less resistance to breakage, resulting in less power consumption. When batch size was larger, naturally, initial power requirement to overcome the resistance of grain was more. The graphs show that the relationship between power consumption and time of grinding is a straight line. The variation of power consumption for different batch sizes and speed of operation could he represented by the following equation (Gautam, 2002):

$$P_b = A + Bt \quad (2)$$

Where,

P_b = log p

p = power consumption, watt

t = time of grinding, sec.

A and B are the coefficient of the above equation.

The value of the coefficient of correlation was in the range of 0.98 to 0.96 with the standard error of experiment varied from 0.26 to 0.43. The coefficient 'A' and 'B' ranged from 1.69 to 1.93 and −0.0009 to −0.001, respectively.

Particle Size Distribution

The size distribution of the water chestnut kernel for different speeds, time of grinding and different batch size was obtained by sieve analysis. Full second order models were fitted for the variation of average particle diameter with the independent parameters. The relationships obtained

Fig. 4 Effect of rpm on power consumption for a 150 g sample and 120 sec of grinding in the batch grinding process

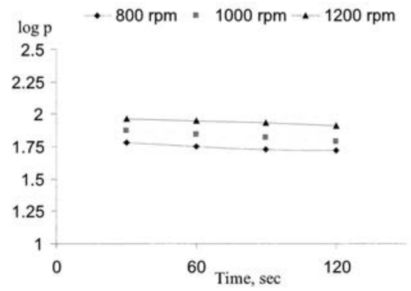


Fig. 7 Effect of rpm on power consumption for a 200 g sample and 120 sec of grinding in batch grinding process

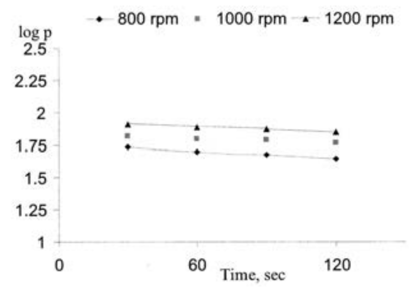


Fig. 10 Effect of time of grinding on particle size distribution for a 100 g batch size and 800 rpm

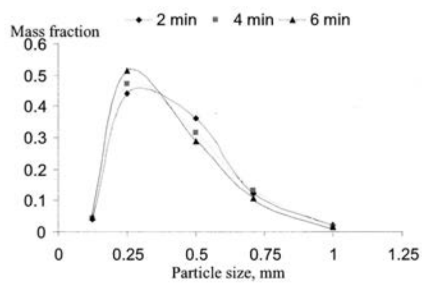


Fig. 5 Effect of rpm on power consumption for a 150 g sample and 240 sec of grinding in the batch grinding process

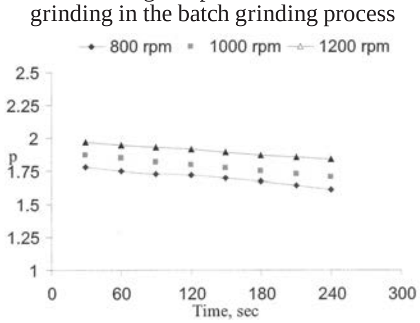


Fig. 8 Effect of rpm on power consumption for a 200 g sample and 240 sec of grinding in the batch grinding process

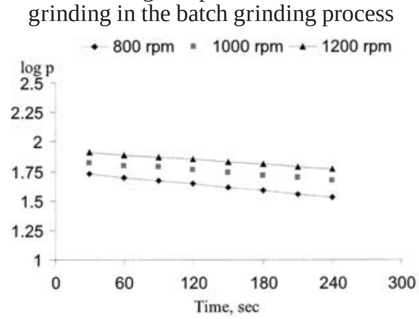


Fig. 11 Effect of time of grinding on particle size distribution for a 100 g batch size and 1,000 rpm

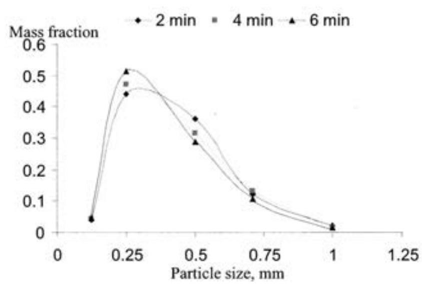


Fig. 6 Effect of rpm on power consumption for a 150 g sample and 360 sec of grinding in the batch grinding process

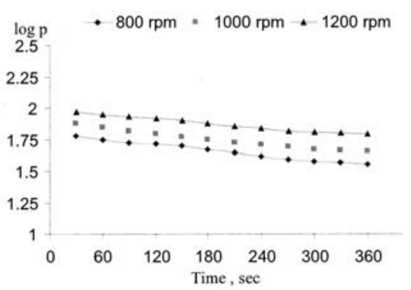


Fig. 9 Effect of rpm on power consumption for a 200 g sample and 360 sec of grinding in the batch grinding process

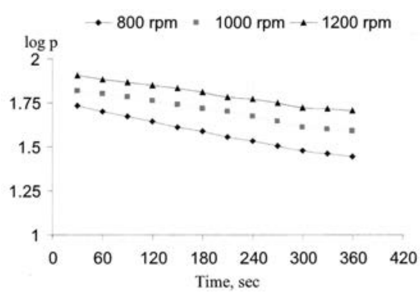
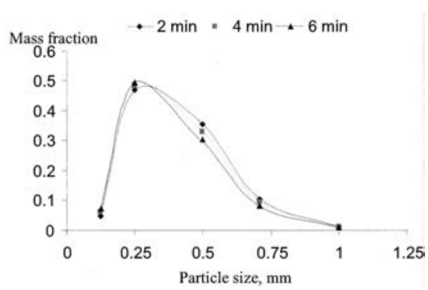


Fig. 12 Effect of time of grinding on particle size distribution for a 100 g batch size and 1,200. rpm



are as follows:

$$P=31.17 - 0.0056X + 0.02476Y + 0.011Z - 0.00043X^2 + 0.0017Y^2 + 0.0024Z^2 - 0.002XY + 0.0045YZ - 0.0005XZ \quad (3)$$

The coefficient of determination (R^2) of **Eqn. 3** was 89.74 %. Thus, the model was acceptable.

The effect of time of grinding, batch size and speed of operation of the mill on particle size distribution is shown by the differential size distribution graphs from **Figs. 10** to **15**. These figures show that as the time of grinding increased the peak of the curves shifted towards the left and magnitude increased also. This reveals that finer particles are produced with time. The mill speed had a definitive effect on particle size distribution of the resultant ground particle. It was clear that for a particular batch size and time of grinding, finer particles were produced in case of higher mill speed. A similar trend was observed for a batch size of 200 g also. Taking mill speed and time of grinding constant, it showed that at higher mass size, less fine particles are produced. However, when the speed of the mill was increased, finer particles were generated.

Fig. 13 Effect of time of grinding on particle size distribution for a 200 g batch size and 800 rpm

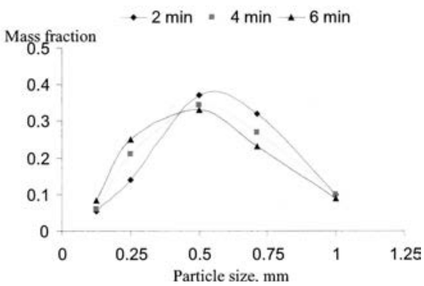


Fig. 14 Effect of time of grinding on particle size distribution for 200 g batch size and 1,000 rpm

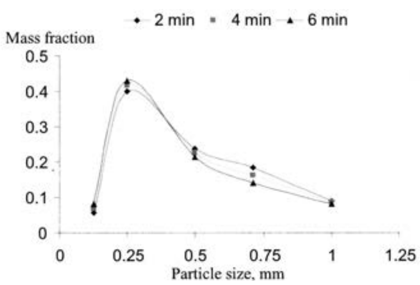
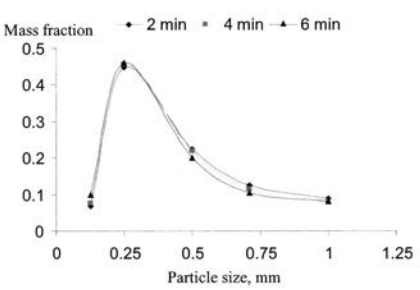


Fig. 15 Effect of time of grinding on particle size distribution for a 200 g batch size and 1,200 rpm



The effect of different times of grinding on size distribution of particles for a constant batch size (100 g) is shown in **Fig. 10** to **Fig. 12**. In these figures, as the time of grinding increased more fine particles were produced. A similar trend was observed for batch sizes of 150 and 200 g also.

It was evident that mill speed had a prominent effect on size distribution of particles since, as it increased, more fine particles were produced. Batch size also had a significant effect on size distribution as represented in **Fig. 10** to **Fig. 15**. Additionally, for lower mass size finer fraction is produced and the situation is similar other operational conditions also.

Modeling of the particle size distribution of the ground product was attempted with the help of curve fitting computer software. The criteria employed for model selection was the value of the correlation coefficient, standard error of estimate and the rationality of the model. Since the software employed had auto fitting ability to rank a particular equation, the criteria for a selection of a model was based on the average rank over the whole set of experimental observations. The following equation called the Harris Model was found to have the best fitting ability amongst the equations available, which satisfactorily correlated the commutative mass fraction with size of the ground material.

$$\Phi = 1/(a + bx^c) \quad (4)$$

where,

x = particle size, mm

Φ = the cumulative mass (%) greater than size x and

a, b, c are the coefficient of **Eqn. 4**

The values of the correlation coefficient for the above mass fraction versus particle size relationship over the whole range of variables were more than 0.96 in most of the cases. The value of standard error of estimate ranged from 0.05 to 0.07. The values of the coefficient 'a' of **Eqn. 4** were found to be in range from 1.09 to 1.01. The values of the coefficient 'b' of varied from 403,261 to 754,515. Evaluation of the data showed that as the time of grinding increased, the coefficient 'a' showed a tendency to increase and as the speed of the mill increases, the value of the coefficient 'b' increased also. The value of the coefficient 'c' increased with of increase of mill speed and time of grinding for a constant batch size and ranged from 9.01 to 12.89. Specific correlations of the variation of coefficients a, b and c with independent variables such as speed, batch size and time of grinding were attempted.

Conclusions

For batch grinding, power consumption was measured for a period of time ranging from 120 sec to 360 sec at various speeds of the mill from 800 to 1,200 rpm for the batch sizes of 100, 150 and 200 gm. The effect of mill speed, sieve size and feed rate was observed on the power consumption. A second order model was fitted for the variation of power consumption with the independent parameters. As the speed of the mill increased, there was an increase in power consumption. In all the cases, initially, power consumption was in higher range and gradually, as time continued, the power requirement reduced to some extent. The relation between power consumption and time of grinding was a straight line. The variation of power consumption for different batch sizes and speed of operation could he represented by the straight line equation.

The size distribution of the water chestnut kernel for different speeds and time of grinding and different batch sizes was obtained by sieve analysis. A second order model was fitted for the variation of average particle diameter with the independent parameters. For a particular batch size and time of grinding, finer particles were produced for higher mill speeds. Taking mill speed and time of grinding constant, fewer fine particles were produced at higher mass size. However, when speed of the mill was increased, finer particles were generated. For all batch sizes, as the time of grinding increased, more fine particles were produced. Mill speed had a prominent effect on size distribution of particles. Batch size also had a significant effect on size distribution. The Harris Model was found to be best fitting for the particle size distribution of the ground product.

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Man-Power Utilization in Some Unit Operations of Dairy Farm

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Introduction

Man-power and energy are the most critical resources which influence the profitability of dairy farming. Judicious use of man-power and energy is the major challenge faced by dairy farmers. Information about the man-power utilization for various dairy farm operations is essential from the viewpoint of man-power deployment and management. The information is also important while farm operations through mechanization are planned either considering the economics of farm operations or maintaining the timeliness of farm operations for profitability.

Man-power contributes approximately 20-30 % of total input cost of dairy farming (Barnard *et al*., 1982). Therefore, to enhance profits of the dairy farm it is an extremely essential requirement to keep a constant control over the labour deployment. It has been observed that, in the dairy farm, availability of labourers may depend on the things such as season, local festivals and weather conditions. Therefore, basic information to decide the deployment of available labour on the basis of priority of different farm operations is perhaps necessary. Apart from it, in the dairy farm timeliness of most of the operations has vital importance as some of these farm operations directly influence the farm profitability. Man-power shortage directly affects timeliness of farm operations and may cause mismanagement of different farm activities leading to economic loss which can be managed, up to some extent, with proper knowledge of man-power utilization in different dairy farm activities.

Each labourer has a certain normal working capacity; however, additional output can be retrieved from workers under emergency conditions as a short term measure. Such measures are necessary, particularly under labour shortage situations, to minimize the economic losses of the farm by maintaining the timeliness of operations and overcoming the immediate hindrances.

Man-power and energy utilization for the dairy farm may depend largely on type, condition and layout of buildings, working efficiency of the labour, species and number of animals maintained, categories of animals, system of milking, feeding practices including types of feed and fodder, pattern of fodder cultivation, distance of fodder field from the animal house and degree of mechanization in farm. More or less, the labour needs are evenly spread throughout the year in dairy farm operations except for the fodder related work (Barnard *et al*., 1982). Thus, minimum man-power utilization of a farm must be understood by the farm manager.

The study of man-power utilization can be summed up as a measure of man-power saving. However, the saving of manpower in the sense of eliminating unnecessary drudgery is also an important issue. Man-power saving alone is much too narrow of a concept and gives the impact that the sole purpose of work study is to eliminate the surplus labour. There are cases when this is the obvious remedy because some dairy farm owners do, in fact, employ injudiciously surplus labour. But in other cases, the most effective and profitable method of improving labour efficiency may be to increase the output with the existing staff or even with a large staff.

The study of man-power utilization is also a method of persuading a person to work harder while having basic information about the minimum work out put of an average worker. On the contrary, the aim is also to eliminate unnecessary work so that more work can be accomplished with less fatigue. This can be considered as 'work simplification' and, in some way, this is a more accurate description than man-power saving.

In India, study of man-power and energy utilization has been somewhat neglected in the field of dairying and other livestock farming. Therefore, very little work has been done and published with respect to the direct applicability at farm level. As a result, labour management in livestock production is based on individual experiences and capabilities. Keeping the above facts in view, the present study has been under taken to ascertain man power required in unit operations of the dairy farm for easy man-power management and assessment.

Review of Literature

Unit operations based information is scantly available for easy man-power management and assessment for livestock farms although many studies have been made on man-power requirement. Review of dairy farms under three areas was made (1) milking operation, (2) cleaning operation, (3) feeding operation and (4) overall man-power utilization.

Milking operation is one of utmost important among the different dairy farm operations. The efficient and rapid removal of milk from the udder in a clean and healthy environment should be the goal of every milking programme. The efficiency of operation is directly related with the capability of the milker, mechanization status and management of milking operations. Baidikov (1977) reported that in farms of the Kharkov region, Russia, labour requirements for milk production under tie-up and cubical loose housing conditions were 28.1 and 17.8 minutes daily/cow, including 12.7 and 7.4 minutes for milking. Corresponding values per 100 kg milk were 6.3 and 5.2 man-hours in tie-up as compared to 1.8 and 1.7 man-hours in cubical loose house conditions. Repka (1978) studied labour expenditure in milk production on 12 large dairy farms each with 240-800 cows. On 6 farms, cows were loose housed and another 6 farms cows were tie-up. The time spent daily/cow ranged from 7.24 minutes in loose housing with parlour milking to 18.91 minutes for tie-up cows milked in their stalls. Time spent on daily milking ranged from 4.05 min/cow to 14.12 min/cow. Nanda (1988) conducted a time motion study on 42 high (> 6.5 liter milk/day) and low (< 6.5 liter milk/day) yielder cross-bred cows and found that morning milking takes significantly longer ($P < 0.05$) than evening milking and high yielding cows required more time at milking than low yielding ones ($P < 0.01$), regardless of breed type (Jersey x red sindhi or Jersey x haryana). Rai *et al.* (1991) reported that among all the operations, time utilization (%) was highest and idle time was lowest in milking. Morning milking required more time, than noon/evening milking. Joshi *et al.* (1992) reported that average time per cow using a milking machine was considerably less than the hand milking which was 7.06 ± 0.03 minutes for morning milking as compared to 14.37 ± 0.602 minute per cow for hand milking. However, the average time required per kg of milk was greater for afternoon milking when the other basic activities associated with the milking operation remained unchanged. Devarajulu and Naidu (1989) reported that milking took about 30 % that included 13.00 minutes for milking of 9.5 kg milk. Bhagat and Sastry (1994) reported that the labour norms for milking and milking associated operations seemed to be approximately 12 buffaloes/labourer/day if twice daily milking was practiced and the milking operations had to be completed in 3 hrs. Aulakh and Gupta (1998) investigated the requirement of labour for milking of cows by hand while conducting time-motion study on 1018 milking performed by 26 milkers in one year. They found that on an average 408.75 ± 3.81 seconds were required to milk 4.14 ± 0.04 kg milk, while season, time of milking and milker had a significant effect on total milking time.

The cleaning operation included time taken for dung and refuse collection, dung and refuse lifting from floor to tractor trolley, floor sweeping and washing, animal washing and cleaning of water trough and manger. Whipp (1976) reported that time required per day per cow for dung removal and handling was 11 % and cubicle littering was 6 % of the total time (4.6 minutes/cow). Coicoiu (1978) analysed labour requirements on dairy farms using different systems and reported that, even with the highest degree of mechanization, a minimum time of 1 minute 30 seconds were required per cow per day for manure removal. Grewal and Rangi (1980) analysed the data available on dairying in Punjab and estimated that sweeping of the animal shed and cleaning of animals accounted for 14-16 % of the total labour requirement of 1.7 hour/animal/day (14.28-16.32 minute/animal/day). Deverajulu and Naidu (1981) studied a dairy farm with 100 lactating cross-bred cows, 24 pregnant heifers and 27 dry animals in a tie-up shed with tail to tail arrangements. The cleaning operation took 24.1, 41.4 and 40.3 % of total labour input for milk animals, dry animals and heifers respectively on a per day basis. Nanda *et al.* (1988) conducted a study on labour requirement in 42 high (> 6.5 kg milk) and low (< 6.5 kg milk) yield cross-bred Jersey cows and revealed that within management operations, the highest percentage of time was consumed in cleaning of cows and byre (34.98 % of total labour working hours i.e.2.27 hrs or 3.24 min/cow) followed by feeding and watering. Joshi *et al.* (1992) conducted a study on man-power requirement while using permanent employees in cleaning operations in IVRI dairy farm having 800 cows and observed that man-hours required for collection of dung using the shovel was 35.84 ± 4.661 man-h/ha area. Whereas 5.27 ± 0.71 bullock-h/ha was required when activity was performed with the help of bullock operated dung cleaner. They found that there was a significant saving in man-power by bullock operated dung cleaner as compared to cleaning of dung by shovel. The man-power required for lifting of dung of wet and semi-dry consistency was 0.896 ± 0.082 and 0.532 ± 0.033 man-h/cu meter of dung while idle time was also taken into account. The manual energy required for lifting wet dung was 0.756 ± 0.059 man-h/cu meter. For washing of lactating cows (without bedding provided at night), 4.96 ± 0.219 man-minute were required per cow. Sharma *et al.* (2006) reported labour utilization patterns under different season and shelter systems (i.e. conventional/tying, semi-loose, loose house) in three groups having 10 cross-bred cows in each group and observed that. In summer, labour utilization was not affected in any of the housing systems but in rainy season, labour utilization for cleaning (62 to 119 man-minutes/day for 10 animals in a group) and other purposes (10.75 to 13.25 minutes/day) differed non-significantly between the groups. In winter season, labour for cleaning (51.0 to 83.75 man-minutes/days for 10 animals) non-significantly differed between the groups.

Responsible sub-activities under feeding operation include fodder chaffing, transportation and distribution of fodder, loading of fodder into manger. Whipp (1976) observed that feeding activities accounted for 16 % of total time (6.4 minute/cow) required in maintenance of dairy cows. Coicovi (1978) studied labour requirements on a Romanian dairy farm using different systems. Daily labour input per tied-up cow yielding 3,000 liters of milk was 15 minutes 44 seconds, of which the fodder distribution accounted for 4 minutes. Grewal and Rangi (1980) analysed the available data on dairy husbandry in Punjab and found that the feeding operation accounted about 19 % of total labour input (1.7 man-h/animal/days). Deverajulu and Naidu (1981) reported that labour input per day for feeding operation accounted for 21.2 % for milk animals, 21.6 % in dry animals and 21.7 % in heifers at Sri Venketeswar Dairy farm, Hyderabad (A.P.). Skiaker (1982) studied 15 Norwegian dairy farms with 12 animals in each farm. He suggested low cost modifications which reduced the net-working day from 339 to 250 man-minutes, with reductions from 104 to 76 man-minutes for feeding. That meant 5.06 man-minute/cow. Agarwal and Sharma (1983) surveyed 1807 households in 61 villages around Karnal (Haryana) and reported that activities associated with feeding accounted about 75 % of total labour time (6.5 h/day). Soliman and Abd-El Monem (1988) analysed the data from 213 traditional farms in Egypt. They estimated that milk producing farms used labour more intensively and 35 % of labour was used for feeding of animals. Singh (1989) conducted time-motion studies on 52 attendants in 453 lactating cows and buffaloes at a cattle yard, NDRI, Karnal, and reported that 10 % of the total attendants were used for fodder distribution to 453 lactating cows and buffaloes which was done with the help of a tractor-trolley. Prasanna (2002) conducted a study on cross-bred female calves in Cattle and Buffalo Farm at IVRI Izatnagar (U.P.) and reported that feeding of milk to calves (18 calves) took 51.54 man-minute (2.86 man-minutes/calf) during the morning, 46.58 man-min in evening (2.58 man-minutes/calf) and greens and concentrate feeding took 24.85 man-minutes (1.38 man-minutes/calf), Thus, a total of 41 % of labour time was utilized for feeding calves. Sharma *et al.* (2006) conducted a study on labour utilization pattern under different seasons and shelter systems in three groups (i.e. conventional tying, semi-loose and loose housing) with 10 cross-bred cows in each group. In summer season, the labour requirement for feeding (55 minutes) in closed housing was significantly higher than in loose housing. In the rainy season, the labour time for feeding in the closed housing group was 61.25 minutes, loose housing group, 25.50 minutes, and loose housing with central shed group, 37.50 minutes. They differed significantly ($p < 0.05$). In winter season the labour for feeding in closed housing was significantly higher (90.25 minutes) as compared to loose housing (30.50 minutes or 3.05 minute/cow).

Repka (1978) studied the data on the time required for care of dairy cows on 12 different farms with 320-966 animals, having different types of buildings, layout, cow management, machine milking systems, methods of cleaning and feed distribution systems. The labour requirement ranged from 7.24 to 20.24 minute/cow (44.77-123.13 h/annum) and 0.67 to 3.10 minute/liter of milk. This enabled one operator to attend to 17.27- 48.20 cows /day. He reported that greatest labour saving was achieved with loose housing that had direct access to the milking parlour. Nanda (1988) found that herd management operations took up more time (52.7 %) than milking (47.3 %). Among the milking operations; post milking took maximum time, 21.19 %, followed by pre-milking, 18.13 %, and milking, 7.98 %. Cleaning of cows and byre took maximum time (35 %), followed by feeding (10.4%) and veterinary treatment and AI services (7.3 %), assuming an 8 hour working. Devarajulu and Naidu (1989) reported that milking operations took about 30 % of total time spent on milk animals under stall feeding and management practices. It was found that daily labour requirement per milk cow was 43.63 man-minutes/day/cows including 13.00 minutes for milking 9.5 kg of milk. The value for heifers and dry animals was 18.0 man-minute/days. Feeding and cleaning operations respectively took 19.3 and 24.1% of total requirements in the management of milk animals; 21.6 and 41.3% for dry animals; and 21.7 and 40.2 % for heifers. The labour required per 100 kg milk produced was 7.77 man-hours and value per animal per annum was 152.00 man-hours.

Material and Methods

The present study was conducted at the Cattle and Buffalo Dairy Farm, Indian Veterinary Research Institute, Izatnagar, to determine the man-power and energy requirements in different farm operations under contractual labourers. The data were recorded without disturbing the normal ongoing routine activities of the farm. The labourers engaged in the livestock farm activities were also not conscious about the recording of data. The study was carried out in different groups of animals, which were basically categorized according to their age or status of animals. These animals were maintained in different sheds of the farm according to their groups. The animals were divided into; 0-3 months calves, 3-6 month calves, > 6 months calves, heifers, dry, advanced pregnant and milk animals. Routine operations like milking, cleaning, feeding and some miscellaneous operations like animal weighing, hot branding, artificial insemination, disbudding and tattooing were observed.

The livestock farm adopted a loose housing system while individual paddock had either brick paving or cement concrete flooring. The collection and lifting of dung and agricultural refuge was basically done manually with a shovel. Broom sticks were used for the cleaning operation. The milking operation was done manually for low yielders in two shifts and high yielders were machine milked in three shifts.

The man power required was evaluated on a unit base. That is, per kg of milk, per 100 square meter area, per quintal of fodder, etc. to have direct applicability for field use.

Results and Discussion

Manpower required in the unit operation of morning and evening hand milking, along with machine milking in morning, afternoon and evening for high yielders was ascertained, which included time required for animal tying and untying, tying and untying of animal legs, udder washing and milking.

Hand Milking

The total time required in per kg of milking operation for different yield group of animals for morning and evening milking is shown in **Table 1**. Total time required for unit operation of morning hand milking (sec/kg milk) decreased with increase of milk yield of animals. Man-seconds utilized in per kg of milking operation of 0-2, 2-4, 4-6, 6-8, 8-10, 10-12 and 12-14 kg milk yield group was 161.50, 123.66, 96.95, 82.60, 66.45, 59.11 and 56.56 seconds per kg of milk, respectively. The average total milking time required for milk yield groups of 0-2, 2-4, 4-6, 6-8, 8-10, 10-12 and 12-14 kg was 323.00 ± 16.90, 439.17 ± 15.07, 523.58 ± 17.73, 581.52 ± 25.65, 608.04 ± 30.13, 644.40 ± 20.47 and 735.40 ± 32.29 seconds, respectively. These groups had an average milk yield of 2.00, 3.55, 5.40, 7.04, 9.15, 10.90 and 13.00 kg milk respectively.

Similarly, for evening milking, milk yield groups studied were 0-2, 2-4, 4-6, 6-8 and 8-10 kg which had an average production of 1.54, 3.48, 4.96, 7.50, and 9.75 kg milk, respectively. The time required for the milking of per kg of milk for these groups was 235.24, 126.93, 99.90, 74.66 and 60.68 seconds, respectively. It was again observed, with increase in milk yield, that the time required in unit operations was in decreasing order, which was due to higher milk flow rates. The total time required in milking operation increased from 362.27 ± 33.50, 441.72 ± 12.04, 495.53 ± 16.11, 560.00 ± 93.00 and 591.66 ± 59.61 seconds, respectively.

Table 1 Time required for unit operation under hand milking

Milk yield group, kg	Average Milk yield, kg	Total milk, kg	Total time required in milking, sec	Unit time, sec/kg milk	Average time/ milking operation
Morning milking					
0-2 (7)	2.00 ± 0.00	014.00	2,261	161.50	323.00 ± 16.90
2-4 (35)	3.55 ± 0.08	124.50	15,371	123.66	439.17 ± 15.07
4-6 (51)	5.40 ± 0.77	275.00	26,703	96.95	523.58 ± 17.73
6-8 (36)	7.04 ± 0.08	253.50	20,935	82.60	581.52 ± 25.65
8-10 (22)	9.15 ± 0.14	201.50	13,377	66.45	608.04 ± 30.13
10-12 (5)	10.90 ± 0.29	054.50	3,222	59.11	644.40 ± 20.47
12-14 (5)	13.00 ± 0.12	065.00	3,677	56.56	735.40 ± 32.29
Evening milking					
0-2 (22)	1.54 ± 0.98	034.00	7,970	235.24	362.27 ± 33.50
2-4 (85)	3.48 ± 0.57	296.00	37,547	126.93	441.72 ± 12.04
4-6 (49)	4.96 ± 0.06	243.50	24,281	99.90	495.53 ± 16.11
6-8 (3)	7.50 ± 0.28	022.50	1,680	74.66	560.00 ± 93.00
8-10 (6)	9.75 ± 0.17	060.50	3,550	60.68	591.66 ± 59.61

Machine Milking

The total time required in the unit milking operation for different yield group of animals for morning, afternoon and evening milking is shown in **Table 2**. It was observed that time required in unit operations (sec/kg milk) decreased with increase in milk yield of animals. Time required in unit operation for 4-6, 6-8, 8-10, 10-12, 12-14 and 14-16 kg milk yield groups was 63.57, 47.56, 41.84, 36.25, 31.53 and 35.72 seconds, respectively. However, the value of unit operation (sec/kg milk) of 14-16 milk yield group was slightly higher than 12-14 kg group, which might be due to experimental errors. The average time of milking operation required for milk yield groups of 4-6, 6-8, 8-10, 10-12, 12-14 and 14-16 kg was 347.10 ± 20.63, 351.05 ± 8.91, 388.74 ± 0.72, 404.62 ± 13.33, 410.00 ± 17.33 and 497.20 ± 32.79 seconds, respectively. These groups had an average milk of 5.46, 7.38, 9.29, 11.16, 13.00 and 14.5 kg, respectively.

Similarly, for afternoon milking, milk yield groups studied were 0-2, 2-4 and 4-6 kg, which had an average production of 1.86, 3.27 and 4.30 kg milk, respectively. The time required for the milking per kg milk for these groups was 143.13, 85.44 and 59.75 seconds, respectively. It was observed that with increase in milk yield the time required in unit operations was in decreasing order. The total time required in milking operations increased from 266.23 ± 13.45, 279.54 ± 3.09 and 292.78 ± 4.11 seconds, respectively.

Observations were also made for evening milking in the above pattern. Yield groups of 0-2, 2-4 and 4-6 kg had an average yield of 1.82, 3.03 and 4.93 kg milk, respectively. The time required in unit operations was 145.33, 90.77 and 63.46 seconds/kg milk, respectively. The trend was, again, observed to be in decreasing order. The total time required for milking operation in these groups were found to be 264.51 ± 9.09, 275.04 ± 5.36 and 312.87 ± 11.41 seconds, respectively.

Cleaning Operation

The man power required in unit operations of cleaning related to animals of different age groups is shown in **Table 3**. The table shows values of man-power required for the cleaning operation for 100 m2 of floor area and also man-power required per animal. The cleaning operation included dung and refuse collection; dung and refuse lifting, sweeping and washing for the shed maintained for 3-10 day old calves, 11th day-3 month old calves, advance pregnant animals and milk animals. However, there was no floor washing activity for 3-6 month calves, >6 month calves, heifers and dry animals sheds. The dung collection activity was carried out with a shovel in all the sheds except the heifer shed in which a patela (a wooden plank 90 × 60 cm with a handle) was used for dung collection while engaging two labourers simultaneously. Moreover, in the calf section the cleaning operation was carried out in calf pens where bedding material as well as dung was swept for achieving necessary cleaning. The calf pens were separated from each other through walls that caused restriction in free cleaning of the pens and ultimately resulted in more time required to clean.

Total man-power required for

Table 2 Time required for unit operation under machine milking

Milk yield group, kg	Average Milk yield, kg	Total milk, kg	Total time required in milking, sec	Unit time, sec/kg milk	Average time/ milking operation
Morning milking					
4-6 (28)	5.46 ± 0.11	153.00	9,719	63.57	347.10 ± 20.63
6-8 (94)	7.38 ± 0.05	694.50	32,999	47.56	351.05 ± 8.91
8-10 (102)	9.29 ± 0.00	948.00	39,652	41.84	388.74 ± 0.72
10-12 (52)	11.16 ± 0.06	580.50	21,040	36.25	404.61 ± 13.33
12-14 (33)	13.00 ± 0.07	429.00	13,559	31.53	410.00 ± 17.33
14-16 (5)	14.5 ± 0.00	072.50	2,486	34.28	497.20 ± 32.79
Afternoon milking					
0-2 (42)	1.86 ± 0.03	78.50	11,182	143.13	266.23 ± 13.45
2-4 (354)	3.27 ± 0.02	1160.00	98,915	85.44	279.42 ± 3.09
4-6 (81)	4.90 ± 0.05	397.00	23,715	59.75	292.78 ± 4.11
Evening milking					
0-2 (56)	1.82 ± 0.03	102.00	14,813	145.33	264.51 ± 9.09
2-4 (155)	3.03 v 0.50	470.00	42,632	90.77	275.04 ± 5.36
4-6 (8)	4.93 ± 0.11	39.50	2,503	63.46	312.87 ± 11.41

Figure in parenthesis indicates the number of observations

Table 3 Overall unit operations of the farm (cleaning operation)

Shed (Age group)	Total man-min*/ 100 m^2 floor area	Man-min required*/animal
3-10 day calves shed	43.50	1.14
11 days to 3 month calves shed	39.79	0.70
3-6 months calves shed	12.65	1.56
6 and above aged calves shed	20.91	2.55
Heifer shed	31.46	4.01
Dry animal shed	13.94	4.54
Advance pregnant animal shed	30.19	5.43
Milk animal shed	30.41	9.65

*Excluding idle time

cleaning of 100 m2 of floor area for sheds; namely 3-10 day old calves, 11 day-3 month old calves, 3-6 month old calves, >6 month and above aged calves, heifers, dry, advance pregnant and milk animals were 43.50, 39.79, 11.65, 20.91, 31.46, 13.94, 30.19, and 30.41 man-min, respectively. These values on a per animal basis were 2.00, 1.14, 1.56, 2.52, 4.01, 4.54, 5.43 and 9.65 man-min, respectively.

Feeding Operation

The man-power, electrical energy and tractor-power required in the unit operation of feeding of oats and berseem fodder is shown in **Table 4**. The table shows the different feeding operations like fodder (oat) chaffing, electrical energy consumed in chaffing, fodder (oat) unloading on floor, fodder (oat) loading from floor to manger, distribution of chaffed oat, fodder (berseem) direct manual loading from trolley to manger and distribution and transportation of fodder (berseem). The time required on unit operation basis was 5.02 man-min/quintal, 0.18 kWh/quintal, 0.84 man-min/quintal, 3.00 man-min/quintal, 1.95 tractor-min/quintal, 2.11 man-min/quintal and 1.36 man-min/quintal, respectively.

Calf Rearing Activities

The over all unit operations in calf rearing activities is shown in **Table 5**. The unit operations for 3rd day-10 th day were described as milk feeding (morning and evening), calf driving out and driving in to the pen, removal of old beddings and application of new bedding material, tattooing and weighing of calves required 7.74 man-min/calf, 1.75 man-min/calf, 1.75 man-min/pen, 4.66 man-min/calf and 4.42 man-min/calf, respectively. on per calf (unit operation) basis.

Operations for 11th day-3 months calves shows that milk feeding (morning and evening), calves driving out and driving in to pens, removal of old bedding, application of new bedding in pens, feeding of concentrate mixture and greens, disbudding and weighing of calf required 1.72 man-min/calf, 0.49 man-min/calf, 1.63 man-min/pen, 0.35 man-min/calf, 13.95 man-min/calf and 7.85 man-min/calf, respectively, on each activity basis.

Miscellaneous Activities

Table 6 shows the man-minutes required in unit operation; hot branding, artificial insemination, animal weighing and animal washing in which on an average of 26.07, 7.40, 2.80 and 4.06 man-min were required respectively.

The total average time spent in morning hand milking of animals yielding 0-2, 2-4, 4-6, 6-8, 8-10, 10-12 and 12-14 kg milk in the morning shift was 323 ± 16.90, 439.17 ± 15.07, 523.58 ± 17.73, 581.52 ± 25.65, 608.04 ± 30.13, 644.40 ± 20.47 and 735.40 ± 32.29 seconds respectively. However, it was 362.27 ± 33.50, 441.72 ± 12.04, 495.53 ± 16.11, 560 ± 93.00 and 591.66 ± 59.61 seconds, respectively, for 0-2, 2-4, 4-6, 6-8 and 8-10 kg milk yield in evening milking.

The total average time spent in milking of different milk yield group of animals in machine milking was 347.10 ± 20.63, 351.05 ± 8.91, 388.74 ± 0.72, 404.61 ± 13.33, 410.00 ± 17.33 and 497.00 ± 32.79 seconds respectively for the animal yielding 4-6, 6-8, 8-10, 10-12, 12-14 and 14-16 kg milk in the morning

Table 4 Overall unit operations of the farm (feeding operation)

Particulars	Man-min/ quintal.	kWh/ quintal.	Tractor min/ quintal.
Fodder (oat) chaffing	5.02	-	-
Electrical energy consumed in chaffing	-	0.18	-
Fodder (oat) unloading on floor	0.84	-	-
Fodder (oat) loading to manger from floor	3.00	-	-
Distribution and transportation of oat	-	-	1.05
Fodder (berseem) direct loading in manger	2.11	-	-
Distribution and transportation of berseem	-	-	1.36

Table 5 Overall unit operations of the farm (calf rearing activities)

Operations	Man-min
3-10 days old calves	
Milk feeding (Morning and Evening)	7.74/calf
Calves driving out and driving in into the pen	1.75/calf
Removal of old bedding material and application of new bedding in pens	1.75/pen
Tattooing	4.66/calf
Weighing of calves	4.42/calf
11 days-3 months old calves	
Milk feeding (Morning and Evening)	1.72/calf
Calves driving out from pens and driving in to pens	0.49/calf
Removal of old bedding material and application of new bedding in pens	1.63/pen
Feeding of concentrate mixture and greens	0.35/calf
Disbudding	13.95/calf
Weighing of calf	7.85/calf

Table 6 Overall unit operations of the farm (miscellaneous activities)

Operations	Man-min/animal
Hot branding	26.07
Artificial insemination	7.40
Animal weighing	2.80

shift. However, time required was 266.23 ± 13.45, 277.35 ± 3.09 and 292.78 ± 4.11 seconds, respectively, for 0-2, 2-4 and 4-6 kg milk yield in afternoon shift of milking and 264.51 ± 9.09, 275.04 ± 5.36 and 312.87 ± 11.41 seconds, respectively, for 0-2, 2-4 and 4-6 kg yield in evening shift of milking.

With increase in milk yield, milking time was also increased but time in unit milking operation (sec/kg of milk) continuously decreased. Time spent in per kg of milk (unit operation) was maximum in evening milking followed by afternoon and morning milking.

Time spent in different groups of animals 3rdday-10th day, 11thday-3 month, 3-6 month, >6 month old calves up to the age of appearance of first sign of heat, heifer, dry, advance pregnant and milk animals on per unit operation of cleaning (100 m^2 area and per animal) basis was observed. The shed of 3rdday - 10th days calves took more time (43.50 man-min) in cleaning the floor as compared to 11thday-3 month old calves (39.79 man-min) because of variation in the characteristics of excreta. There was a continuous increase in the cleaning time from 3-6 month shed to heifers which increased 11.65 to 31.46 man-min per 100 m^2 area. Similar trends of cleaning operation per animal was also observed, which increased from 1.56 to 4.01 man-min per animal.

Time required in oat chaffing, unloading of chaffed oat from tractor trolley, loading of chaffed oats to mangers from ground and loading of berseem directly to mangers from trolley was 5.02, 0.84, 3.00 and 2.11 man-min/quintal of fodder. The electrical energy consumed was 0.18 kWh/quintal of chaffed fodder. The tractor requirement for transportation of fodder was 1.05 and 1.36 tractor-min/quintal of fodder for oat and berseem. Milk feeding required 7.74 man-min/calf for calves up to 10 days of age and 1.72 man-min/calf for calves ranging from 11 to 3 months of age for milk feeding. Disbudding operation required 13.95 man-min/calf.

The miscellaneous activities like hot branding, artificial insemination, animal weighing, animal washing required 26.07, 7.40, 2.80 and 4.06 man-min/animal, respectively.

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Design and Testing of an Avian Hatchery Solar Energy Incubator for Smallholder Poultry Farmers from the Sudano-Sahelian Belt

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Abstract

The small scale (smallholder) poultry farmers of Burkina Faso face numerous challenges, one of which is lack of non-electric effective incubators with which to hatch chicken and guinea fowl eggs. The purpose of this paper was to evaluate the technical and economic feasibility of a cleaner alternative renewable energy powered incubator for a typical smallholder poultry farmer from the Sudano-Sahelian Belt with the central Burkina Faso as the model region. A solar powered system was designed based on the loading of two GQF Hova-BatorTM 2362 incubators. A BP Solar 3125U solar panel was chosen to accommodate the required loading based on the high solar energy in Burkina Faso. In addition, an ASC charge controller, UniRac solar mount, Exeltech inverter, and Concorde PVX 1040T deep cycle battery were chosen for the 80 watt load. Based on economic analysis, at full capacity (180 eggs), annual income was estimated at $4,127 with a net present value of $24,228 at 15 % interest. This included battery replacement every 5 years. Payback period was estimated at 5 months with benefits to cost ratio of 14.9. The Internal Rate of Return of 238 % suggested the proposed incubator system to be an extremely attractive option for the smallholder poultry farmers in the Sudano-Sahelian Belt. The system was implemented in Burkina Faso and guinea fowl hatchabilities of 64.6 to 76.0 % were obtained.

Introduction

Burkina Faso is the third poorest country in the world with 72 % of its 13.5 million inhabitants living below the poverty line. Burkina Faso lies within the Sudano-

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Sahelian Belt, the most fragile and least favorable ecological zone for development in all Africa (World Bank, 1996). Agriculture makes up most of the country's economy; industry is dominated by government controlled corporations (CIA World Fact Book, 2005). About 90 % of the population engages in subsistence (smallholder) farming, many of these living in small villages and farming communities without access to electricity. Poultry production, where eggs are incubated and hatched naturally by the mother hen, is one of the few sources of income for many smallholder farmers. However, the poultry industry is very small with 24 million domestic chickens and 6 million guinea fowl (Tamboura, 2005).

Burkina Faso's strategic geographic location, bordered by six countries, creates a very high demand for meat and other products. However, the poultry industry has not been stable and efficient enough to profitably capitalize on this demand.

In addition to poultry's significance as a food source in the Burkina economy, chickens and guinea fowl (GF) also play a significant cultural role in ceremonies and feasts. While chickens are produced year round, GF have a seasonal cycle and do not brood over their eggs, creating additional demand for incubators.

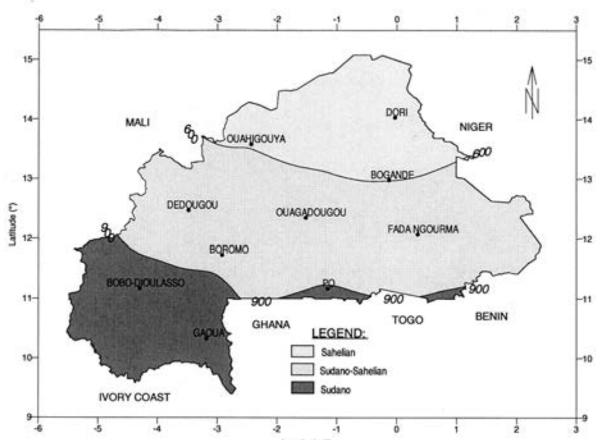
The smallholder poultry farmers face numerous hardships. For example, the harsh conditions for the traditional means of production make their birds vulnerable to diseases such as Newcastle, Gumboro, and parasitic diseases (Ouedraogo, 2005). They are hampered by limitation imposed by the number of eggs that can be incubated by a hen. Additionally, the recurring droughts and the high year round temperatures (high average of 103 ºF) make water a scarce resource and proper egg storage for incubation difficult to attain.

Recently, a nongovernmental organization, Albert Schweitzer Ecological Center, introduced an incubator with the goal of increasing the productivity of the smallholder poultry farmers. The incubator is locally manufactured and is based on a design similar one that used to be manufactured by the Prairie State Incubator Company of America in the 1930's and costs approximately $180. The incubator is powered by a kerosene lamp heat source and a steel pipe heat exchanger. Water is heated by the kerosene flame and by convection flows through galvanized steel pipes over the egg incubation area. The eggs are heated by radiant heat from the pipe, simulating natural incubation. A simple mechanism allows the eggs to be turned 45º periodically throughout the day by the operator. A heat sensitive diaphragm sensor placed inside the incubator serves to relieve high temperatures when needed by lifting exhausting warm air. Evaporation trays at the bottom of the incubation area provide the necessary humidity levels, while a mercury thermometer displays the inside temperature. The incubator is constructed out of wood and contains a 1/2 in. thick fiberglass-like insulation layer. Its dimensions are 4.6'L × 2.0'W × 1.1'H and can hold up to 200 eggs.

The success of the incubator in Burkina Faso has been mixed. In three trials in Gampela village, a well trained farmer reported 25 %, 19 % and 0 % hatchability rate, respectively. Furthermore, hatched chicks showed signs of malformations and other traits of weakness that eventually led to mortality rates as high as 99 %. The farmers interviewed complained of difficulties in maintaining a constant temperature and of frustrations in properly managing the kerosene lamp. The interviewed farmers recounted having to tend to the incubator during night hours and being irritated by the smoke produced by the kerosene lamp. Also, the kerosene cost was considered by farmers to be excessive. Taken together, the farmer's testimonies suggested that poor performance of the incubators could be due to a combination of improper storage of eggs before incubation (too long at high ambient temperatures) and failure to control the incubator temperature within the required range for hatchability.

The purpose of this paper was to evaluate the technical and economic feasibility of a cleaner alternative renewable energy powered incubator for a typical smallholder poultry farmer from the Sudano-Sahelian Belt with the central Burkina Faso (**Fig. 1**) as the model region.

Fig. 1 Climatologic regions in Burkina Faso



Incubator System Concepts

To meet the needs of the small-holder poultry farmer, the incubator design must maintain optimal air quality conditions during incubation periods, embrace the principles of appropriate technology/sustainable design, improve hatchability, and must be safe to operate. The three most important factors for successful poultry production are maintaining a uniform and constant temperature (101.5 °F), optimal humidity (between 50 % and 60 % in earlier stages; increased to 75 % in later stages) and air quality levels (between 0.4 % and 0.6 % CO_2) (Cobb-Vantress, 2002). Also, eggs must be turned throughout incubation to prevent the embryo from sticking to shell membranes and so that the embryonic membranes develop correctly (Smith, 1997). Customer-required attribute analysis based on a survey of stakeholders and their ranking is presented in **Table 1** and conceptual solutions considered are presented in **Table 2**.

As indicated in **Table 2**, use of photovoltaic cells to produce electricity from the sun for a commercially available incubator was highly favorable. This concept rated the highest in concept analysis considering the composite weights of the stakeholders and attributes. With the availability of electricity, the appropriate incubator can be selected to provide temperature, humidity, and the air quality needs of the eggs. This concept particularly differed from the others in that it addressed the issue of egg storage; by providing a smaller capacity incubator, the farmers can have overlapping and multiple incubation cycles that will reduce the amount of time required to store eggs at ambient temperatures before incubation.

Design and Details

A schematic of the proposed system is shown in **Fig. 2**. Design/selection details for each component are presented below. Average solar insolation levels in Burkina Faso as recorded over 33 years in Sudano-Sahelian (central) Region were obtained from the Climate Center (Ouattara, 2005).

Incubator

The HOVA-BATORTM incubator (Model 2362, GQF Manufacturing Company, Savannah, Georgia) was found ideal for this application. It is small (18 × 18 × 7 inches), simple to operate, competitively priced and holds up to 90 small eggs or 70 large eggs. Given the small egg sizes of the Burkina Faso chicken, two incubators, with a combined capacity of 180 eggs comes close to the 200 egg capacity of the current design.

Average Amp Hours Per Day

Using two HOVA-BATOR incubators and assuming loss correction factor of 1.25 (Advanced Energy, 2005), the total Amp Hours/Day was calculated to be 33.3 as shown below.

AC loads run by inverter

2 (Incubators) × 40 (Watt) × 28 (Hrs/Week) = 2,240 (Watt Hrs/Week)

Correction factor for inverter loss and battery efficiency

Table 1 Customer required attribute analysis and composite weight distributions

KEY	Rank
Maintaining uniform and constant temperature	1
Maintaining optimal humidity level	2
Maintaining optimal air quality level	3
Low Initial Cost	8
Low Operational Cost	7
Low Maintenance Cost	9
Durability	6
Ease of Use	5
Satisfying Size Constraints	12
Egg Capacity	11
Self Regulating	4
Satisfy 21 Day Incubation Period	10

Fig. 2 Schematic of the proposed solar incubator system

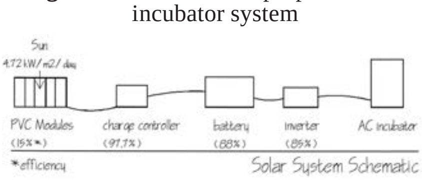


Table 2 Energy sources and design concepts considered

Concept and/or Energy Source	Comment
Fitting the current incubator design with a thermal regulator and storing eggs in evaporative coolers (Abba, 2005) prior to incubation.	While this concept can improve temperature regulation and egg quality, it does not adequately address the smoke problem from the kerosene lamp.
Electric incubator powered by fossil-fuel (gasoline) generator.	Capital and maintenance costs associated with gasoline-powered generators are prohibitive.
Multi-Stage Incubation - where eggs are placed in the incubator as collected.	The benefit of this concept is that eggs that are further in the development cycle can provide enough heat to fulfill the need of the younger developing embryos. The down side to this concept is the detailed management that is a must for successful operation.
Powering a simple electric incubator with wind energy.	Despite the natural attractiveness, the initial cost is prohibitive and extended periods of absence of wind in the region reduced interest in the concept.
Simple electric incubator powered by solar energy (photovoltaic cells).	This approach rated highest in concept analysis. It differed from other concepts with respect to moderate capital investment, use of multiple small incubators that address the egg storage issue, year round energy availability, and sustainability.

$\eta_1 = 1.25$

Corrected total watt hours used per week

1.25 × 2,240 (Watt.Hrs/Week) = 2,800 (Watt.Hrs/Week)

Input voltage of inverter

V = 12 (Volts)

Total amp hours used per week by AC loads

2,800 (Watt Hrs/Week) /12 (Volts) = 233.3 (Amp Hrs/Week)

Total amp hours used per day by AC load

233.3 (Amp Hrs/Week) / 7 days = 33.3 (Amp Hrs/Day)

Photovoltaic Solar Panels

The solar panels are made of silicon, which converts sunlight into an electric charge. Normally solar panels are placed at an angle equal to the latitude of the site, which in the case of Burkina Faso is 13º. The panels collect the charge, which is then transferred to output terminals through wiring to produce a direct current (DC) between 6 and 24 volts. The amount of energy collected by the solar panel is dependant on the insolation or peak sun hour's incident on the area. At peak sun, 1000 W/m^2 of power reaches the earth's surface in one hour of a cloudless day. The lowest average value of insolation obtained through the Meteorological Center in Ouagadougou, Burkina Faso was found to be 7 hours in the central region of Burkina Faso (Ouattara, 2005). As shown in the calculation below, a total solar amperage of 5.7 was obtained.

Correction factor for loss from battery charge and discharge

$\eta_2 = 1.2$

Corrected total amp hours used per day by AC loads

33.3 (Amp Hrs/Day) × 1.2 = 40 (Amp Hrs/Day)

Total solar amps required

40 (Amp Hrs/Day) / 7 peak sun hours = 5.7 (Solar Amps)

Any solar module with a peak of 7.1 amps (e.g., British Petroleum model # 3,125 solar modules: 151.0 cm long, 67.4 cm wide, and 5.0 cm deep; 12.0 kg by weight; 36 solar cells; 125 W maximum power; 17.6 V at peak power) should satisfy the solar amp load. Because the DC input voltage inverter was chosen to be 12 volts, only 1 module is needed in a series string to provide the necessary DC battery voltage as opposed to 2 modules for 24 volts or 4 modules for 48 volts. Connecting the modules in series increases voltage but maintains constant amperage, but if the modules were connected in parallel, voltage would maintain constant and amperage would increase. Mounting of solar panel can be done on ground or on rooftop.

Inverter

An inverter is necessary to convert the DC power from the battery to 120 or 240 AC voltages that is normally used in most electrical devices that are plugged in. The inverter conditions the DC signal to produce the appropriate and usable energy waveform needed by the electrical device. The inverter however dissipates energy through the process of conditioning the signal resulting in undesirable losses. The specification used to choose an inverter is continuous watts, which are the amount of total watts multiplied by a surplus factor of 1.5-2.0 that the inverter can support for extended periods of time. In this case 160 Watts was calculated as shown below.

Continuous wattage required

2 (Incubators) × 40 (Watt) × 2.0 (Surplus factor) = 160 Watt

The pure sine wave inverter such the Exeltech (Fort Worth, Texas) Model #XP-250-12 (33.1 cm long, 13.3 cm wide, and 7.4 cm deep; 3.9 kg in weight; 1,000 Watt and 8 Amp rms) was chosen to deliver the 160 watts needed to run the two incubators at the same time and allow for expansion of additional electrical components which may feed from the inverter. The inverter converts 12 DC volts into 120 AC volts at 60 Hz.

Battery

When developing a solar powered system, lead-acid deep cycle batteries are crucial to reduce costs and maintenance. Deep cycle batteries can be drained and recharged thousands of times. Batteries allow for the storage of energy to be used whenever electricity must be supplied to a load. Also, in periods where no sun is available to power a solar powered system, a battery acts as a reserve for the system to function regardless of the lack of solar input. Factors that may affect sizing of the battery are required storage capacity, maximum charge rate, and minimum temperature at operation. Due to the year round high temperatures in Burkina Faso, minimum temperature at operation is not a factor.

Total amp hours used per day by AC loads

233.3 (Amp.Hrs/Week) / 7 days = 33.3 (Amp Hrs/Day)

Maximum continuous cloudy days expected in area = 2

Max amp hours needed

33.3 (Amp Hrs/Day) × 2 days = 66.6 (Amp Hrs)

Correction factor to maintain a 20% reserve after deep discharge period = 0.8

66.6 (Amp Hrs) / 0.8 = 83.25 (Amp Hrs)

Maximum output amperage of PV array = 7.1 (Amp)

High charge current special condition

7.1 (Amp) × 10 (Hrs) = 71.1 (Amp Hrs)

The calculations above indicated that the battery should be sized to satisfy the largest rating of 83.25 (Amp Hrs). The Concorde Battery Corporation (Covina, CA) Model #PVX-1040T (30.6 cm long, 16.8 cm wide and 22.7 cm deep; 30 kg in weight) with a 24 hour rate of 104 capacity (Amp*Hrs) was chosen because of its relatively low cost, maintenance-free, dependable design. It also features a self discharge rate of 1 % per month at 25 ºC.

Charge Controller

A charge controller is utilized in a solar powered system to monitor and control the charge and discharge of a battery. The controller protects the solar panel and battery from damage by ensuring that the battery is not overcharged or drained too far. In times of no sun exposure, it prevents the battery from the tendency to drain itself by disallowing the higher voltage potential in the battery to flow to the lower voltage potential in the uncharged solar arrays (Online Solar, 2005). Sizing the controller is dependant on the maximum amperage from the solar panel. A Specialty Concepts, Inc (Chatsworth, CA) charge controller, Model #ASC 12/8 (11.94 cm long, 6.35 cm wide, 3.18 cm deep and 0.25 kg weight) with nominal voltage and amperage of 12 and 8, respectively, was found adequate. It should be pointed out that it is possible to eliminate the controller by including a couple of "check valve" diodes in the circuit.

Overall System Efficiency

Fig. 3 shows a picture of the system components assembled. The specification sheet of the Exeltech Model #XP-250-12 inverter indicates that the typical efficiency at full power is equivalent to 85 %. BP Solar modules claim that their performance multicrystalline enhanced cell coating enables the solar cell's efficiencies to convert 14-15 % of incident insolation into electricity. Specialty Concepts, Inc. ASC 12/8 charge controller specifies that at maximum array voltage of 26 volts, the maximum voltage drop from the array to the battery is 0.55 volts, and the voltage drop to the load is 0.06 volts. From these figures a controller efficiency of 97.7 % was calculated

(26 Volts-.55 Volts-.06 Volts) / (26 Volts)

Typical lead-acid batteries efficiencies range from 85-95 % (The Ultimate FAQ Deep Cycle Battery Basics Information, 2005). Taking the median value of the range and subtracting 2 % to account for self-discharge per day, the battery efficiency was found to be 88 %. Adding up all of the loss efficiencies for the charge controller, battery, and inverter, it was found that the system loses about 30 % of the energy collected by the solar array before it is delivered to the incubator.

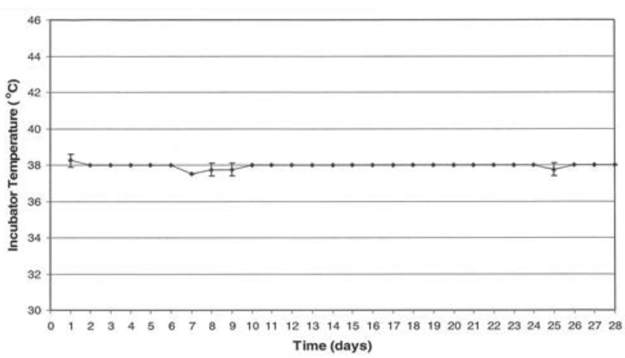
System Testing in Burkina Faso

Two incubators were taken to Burkina Faso for testing to determine hatchabilities of GF. These incubators were powered by photovoltaic solar panels. A farmer was given instructions for operation, and placed 25 eggs in the first incubator and 65 eggs in the second incubator. It was not possible to fill the incubators to capacity due to low availability of viable eggs; the experiments were conducted during the dry season, when GF laid fewer eggs. The incubators were placed inside a typical farmer's house with windows for acceptable ventilation. The eggs were candled around day 10, and infertile eggs were removed. Dry keets were removed and placed in pens.

The system implemented in Burkina Faso differed from the original design in that the incubators were modified by replacing the original AC with a DC motor. This eliminated the need for the inverter. The system was powered by solar energy, controlled the incubator temperature exceedingly well as shown in **Fig. 4**. The slight drop in temperature between days 7 and 9 was due to cloudiness. With this system, hatchability results of 19 (76.0 %) for the incubator containing 25 eggs and 42 (64.6 %) for the incubator containing 65 eggs were obtained. These results were lower in comparison to previous ex-

Fig. 3 Solar energy incubator system components assembled with one incubator and two batteries

Fig. 4 Average temperature as a function of time in Burkina Faso



periments performed with GF eggs. Ancel *et al*. (1994) performed an experiment using 8,000 GF eggs to obtain the hatchability rates for eggs at optimal incubation conditions; hatchability rates ranged from 78 % to 81 %. In Zimbabwe, an average hatchability rate of 71.2 %, with a standard deviation of 14.2, was determined by smallholder farmers (Saina *et al*., 2005). Hatchabilities averaging 83.1 % with a standard deviation of 8.7 were seen in Burkina Faso by Pousga and Boly (2005). The lower hatchability results in this study were attributed to poor egg quality. Eggs were bought from the open market without any knowledge of their age or the storage conditions.

Table 3 Breakdown of system initial costs

Item	Cost (USD)
BP Solar 3215U	555.00
ASC Charge Controller	45.60
Concorde Sun Xtender PVX1040T Battery	157.95
Exeltech XP Inverter	403.00
Battery Wiring	47.00
System Wiring 60’	62.00
UniRac Solar Mounting	152.00
Hova Bator 2,362 (2 Units)	136.50
Sub-Total	$1,559.05
Taxes (7%)	109.13
Shipping Total	50.00
Assembly Cost	30.00
Total	$1,748.18

Table 4 Economic analysis

Factor	Value
Lifetime	20
Burkina Faso Interest Rate	15%
Salvage	0
Annual Predicted Income	$4,167.00
Lifetime Predicted Income	$81,384.00
Present Value Cash Flow	$25,976.13
Net Present Value	$24,227.95
Payment	$279.29
Payback (yrs)	0.42
Benefit/Cost Ratio	14.86
IRR (%)	238%

Economic Analysis

The breakdown of the complete system initial cost is presented in **Table 3**. For the economic analysis, a full capacity (180 eggs) operation, 80 % hatchability, and selling price of $1.55 per hatched chick were assumed. Also, the system life of 20 years, interest rate of 15 %, and a five-year battery replacement cycle at $157 a piece were assumed. The 20-year lifetime was based on the lowest warranty estimate. The results of the economic analysis are presented in **Table 4**. Net Present Value of $24,228 and Internal Rate of Return of 238 % were obtained. Payback Period and Price to Cost Ratio of approximately 5 months and 14.9:1, respectively, were obtained. In the calculation, operational costs were assumed to be zero; no monetary value was attached to labor to turn eggs.

Concluding Remarks

By supplying 2 units of a small capacity incubator, which allows overlapping incubation cycles, the amount of time between laying of eggs and beginning of incubation is reduced. This, in effect, prevents premature embryo development at high ambient storage temperatures that might have been responsible for the high mortality rates observed in the Gampela village incubator trials. At a total initial cost of $1,587, a net present value of $24,389 and payback period of 0.38 years, this solution offers an economically feasible and profitable operation.

The initial cost on the system can be reduced by 25 if a DC incubator is used. Internet search did not yield any commercially available DC incubators. However, the HOVA-BATOR can be converted to DC. The main uncertainty in the assumptions made is the 80 % hatchability. Since the HOVA-BATOR is designed for the North American market, initially it was not clear if it would perform as well under typical Sudano-Sahelian ambient temperatures. However, in further studies GF hatchability in Burkina Faso have confirmed the system performance at high ambient temperatures.

The initial capital cost to implement this system is generally out of reach of the target smallholder farmers. One possible approach is to engage a NGO that would provide the system and in return the smallholder farmer make monthly payments in kind (e.g., provide a fraction of the hatchings to the NGO, which are sold to farmers) The NGO would also provide training for proper operation of the equipment and business management. By serving many farmers, the NGO would build capacity to absorb occasional losses (e.g., when too many keets are lost due to human error). With current social entrepreneurial funding such as the World Bank Development Market Program, NGOs with development track record are in good position to raise the kind of capital needed to serve many farmers like the ones targeted in this study. Equipment vendors can also play the “middle man” role.

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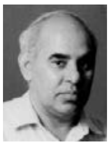
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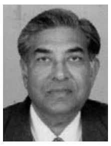
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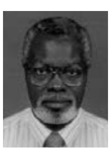
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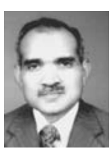
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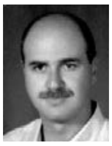
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