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EDITORIAL

Burst of the economic bubble has made the U.S. economy melt down, which escalated into a chain reaction and global economic downturn. Under such difficult conditions, China has still sustained high growth rates and, what is more, China has even alleviated the effects of the economic crisis. If this economic growth keeps up for the next 20 years, in 2030 the per capita national income of China will be the same as that in USA now. It is horrifying to imagine what would happen then. The USA today eats up many resources and, if China in 2030 does the same thing, resources such as paper would drain and might cause extermination of the forests. Regarding the food problem, consumption of meat would get larger and larger, and a huge demand of grain would occur at the same time. This would have a large scale influence on world agricultural trade.

People in all developing countries and rising nations, in addition to China, want to live in prosperity. It is hard to stop that type of hope. However, the earth has reached its limit because of the burst of population and the globalization of economic activities. Humans are born within a life system and must coexist within it to survive on earth. We couldn't live without this system. But, humans have destroyed the system too much. It is in question how to revive this system and how we can be in harmony with it. Especially, the food problem is the biggest of all. The land area per farmer is decreasing every year. To stabilize the supply of safe agricultural products within the limited area of land, we must increase the productivity per unit area. We must also continue to consider environmental safety. This presents a new task for agricultural mechanization. Crop yields must be increased by using agricultural machines appropriately as they perform specific tasks. Also, all intellectual strengths must be utilized to develop agricultural machines with power to perform each task with the least energy consumption. Within the concept of precision agriculture, there are already some machines that are accomplishing this. They can be seen in some agricultural machinery markets today. Taking a long-term view, agricultural mechanization is changing from the development of muscle power to the utilization of intellectual abilities to more efficiently power agricultural machines and operations. I hope this change can be more effectively activated. Many types of large machines exist today that boost production. Intellectual abilities, appropriately applied, can identify machines and methods for increased production that do not require such gigantic machines. The problem of soil compaction would be solved at the same time. Also, a large agricultural field would not be necessary to use small, intellectually designed machines. Small, dispersed types of farming land, or even sloped lands, are not a problem at all for them. One way to harmonize with vital systems is to apply mechanical intelligence to agricultural machines and create a new production system using small, intellectual machines. Of course, this system should be good for the life system.

We must also care about simple, life sustaining, economic food of high nutritional quality for consumption in moderation. In many developed countries, the problem of obesity is raising the cost of healthcare. We should, once again, recognize that not only producing, but also using the limited food appropriately, is one way to solve the food problem. The world is getting smaller, but the gap between rich and poor is getting wider and wider, and so is the technical gap. We must create a new technology for the prosperity of the people in developing nations. If various gaps get wider than they are now in this small world, many people will suffer from stress, and dissension could not be prevented. We must all care about how to press forward with agricultural mechanization in developing nations and provide technical assistance. That is the appointed work of AMA. We truly hope for the readers of AMA to make efforts to achieve their goals.

Yoshisuke Kishida
Chief Editor

November, 2010

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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Effect of Different Machinery on Rice Crop Establishment and their Influence on Subsequent Wheat Crop in India

by

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Abstract

A field experiment was conducted during 2003 to 2006 to study different machinery for the establishment of rice (*Oryga satva L.*) and the effect on subsequent crop growth, productivity and energy. The study was made for direct seeding (dry bed), drum seeding (wet bed), mechanical transplanting (puddled and unpuddled) and manual transplanting (puddled) in subsequent crops of wheat. The mean yield of hybrid rice was higher (8.52 t/ha) with drum seeding (wet bed) that was at par with direct seeding (dry bed) and mechanical transplanting (puddled) as compared to manual transplanting (puddled) and mechanical transplanting (unpuddled). Direct seeding (dry bed) adopted in previous rice crops gave higher mean yield of wheat (5.70 t/ha) followed by drum seeding (wet bed), mechanical transplanting (unpuddled), manual transplanting (puddled) and mechanical transplanting (puddled). The net return energy of the system was high in drum seeded (170,926 MJ/ha) followed by direct seeded (169,070 MJ/ha) and lowest of 150,542 MJ/ha in manually transplanted (puddled). The drum seeded rice required 3.6 % less input energy and gave 8.9 % higher output energy, whereas, direct seeded required 2.6 % less input and gave 8.2 % higher output energy as compared to manually transplanted (puddled). The direct seeded (dry bed) and drum-seeding (wet bed- unpuddled) saved irrigation water by 13 to 19 % when compared to manual transplanting (puddled).

Introduction

Traditionally, rice (*Oryga satva L.*) is grown followed by wheat (*Triticum aestivum L.*) in India (*Sharma et al., 2004*). The rice-wheat system is a predominant cropping system of the Indo-Gangetic Plains regions, where rice is mostly grown by transplanting 21 to 35 day old seedlings in puddled fields. The disadvantages this technique is that it is labour intensive and requires continuous ponding of the water for the first fifteen days. It leads to nutrient loss through de-nitrification, leaching and evapo-transpiration during the hot summer. Moreover, transplanting by unskilled contractors often leads to sub optimal plant population (16-22 hill/m^2) compared with recommended populations (35 hills/m^2). Continued puddling over decades has led to deterioration in soil physical properties through structural breakdown of soil aggregates and capillary pores and clay dispersion. Puddling forms a puddled layer and a plough pan at about 15 to 20 cm depth that restricts water movement causing temporary water logging and restricted root penetration and growth for succeeding crops after rice (*Meelu et al.*, 1979; *Kirchhof* and *So*, 1996). It is, therefore, important that alternative methods that are less water-efficient and less labour-intensive be developed to enable farmers to produce more at less cost. One way to reduce water demand is to grow direct dry-seeded rice (DSR) instead of the conventional puddle, transplanted rice. Direct dry seeded rice avoids puddling, does not need continuous submergence and, thus, reduces the overall water demand for rice culture. In South Asia, DSR is being practices in medium-deep and deep water rice ecologies of the eastern Gangatic plains of India and Bangaladesh, and on terraced and sloping lands in the northeastern and northwestern Himalayan region and western Ghats along west coasts of India (Timsina and Connor, 2001). The area of direct seeded rice in India, Pakistan, and Bangladesh is 4.2 million hectare. Thus, DSR occupies 26 % of the total rice area in South Asia (*Gupta et al., 2006*). Productivity of DSR is often reported to be comparable with transplanting (*De Datta,* 1986). As per the above advantages of growing direct dry-seeded rice (DSR) instead of the conventional puddled transplanted rice, the intervention of the machineries are definitely required to evaluate the different DSR machines and compare with a transplanter. Therefore, the present experiment was to study the effect of different machines on crop establishment and the growth and yield of hybrid rice and a subsequent crop such as wheat and the resultant energy input and output.

Materials and Methods

Site Characteristics

A for 3 year (2003 to 2006) field study was conducted at Project Directorate for Cropping Systems Research, Modipuram, Meerut, U.P., India (29^{o} 4' N and 77^{o} 46' E) at an elevation of 237 m. a. s. l. The climate of Modipuram is semi-arid subtropical, characterized by very hot summers and cold winters. The hottest months are May and June (maximum temperature 45-46 ^{o}C), whereas during December and January, the minimum temperature often goes below 5 ^{o}C. The average annual rainfall is 863 mm, 75-80 %, which occurs through the northwest monsoon during July-September. The soil of the experimental field was sandy loam in texture (64.2 % sand, 18.5 % silt and 17.3 % clay) (Typic -Ustochrept), pH 8.1, electrical conductivity 0.42 ds/m, organic carbon 0.49 %, available nitrate nitrogen 74 mg/kg, Olsen P 12.6 mg/kg and 69.1 mg/kg of available K.

Treatment

The four treatments were in rice crop established by different machineries along with their tillage levels and the fifth treatment was the conventional method of rice transplanting as practice by farmers. The treatments are presented as below.

T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking) − dry bed

T_2: Drum seeding (2 harrow + 2 cultivator + 2 planking) − wet bed

T_3: Mechanical transplanting (2 harrow + 1 planking +2 passes of puddler) − puddled

T_4: Mechanical transplanting (2 harrow + 2 planking) − unpuddled

T_5: Manual transplanting (2 harrow + 2 cultivator + 1 planking + 2 passes of puddler) − puddled

The succeeding crop; wheat with common tillage operations (2 harrow + 2 cultivator + 2 planking) was evaluated in randomized block design with four replications. Hybrid rice (cv. PHB 71) was sown 20 cm apart with a seeding rate of 40 kg/ha. Wheat (PBW 243) was grown 20 cm apart at a seed rate of 100 kg/ha. The gross plot size was 33 m × 4 m for rice and 10 m × 4 m for wheat

Table 1 Technical specifications of self- propelled rice transplanter

Items	Specifications
Model	2 ZT-238-8
Dimension (L × W × H), cm	241 × 213.1 × 130
Engine power, kW	2.4
Fuel	Diesel
Cooling system	Air cooled
Weight, kg	320
Walking mechanism	Single wheel driven
Type of float	Fiber glass
Working mechanism	Separate crank connecting rod transplanting mechanism
Number of rows	8
Row spacing, cm	23.8
Hill to hill spacing, cm	10, 12 and 14
Frequency of transplanting, strokes/ min	238
Depth of transplanting	Adjustable with screw rod (2 to 12 cm)
Traction wheel	
a) Diameter, cm	70
b) No. of lugs	15
c) Lug angle, degree	22 upward
Frequency of strokes of fingers in maximum displacement of tray, no.	14
Max. depth of finger entering the mat, cm	1.7

Table 2 Technical specifications of drum seeder and zero-till drill

Items	Drum seeder	Zero-till drill
Make	CRRI, Cuttak	National Agro machineries, Ludhiana
Type	Manually operated, pre-germinated paddy	Inverted-T type furrow opener
Power source	Two persons	Tractor
Number of rows	8	9
Row spacing	20 cm	22 cm
Overall dimensions		
Length	1,425 mm	1,850 mm
Width	750 mm	600 mm
Height	670 mm	1,450 mm
Weight	16 kg	250 kg
Depth of seeding	Surface of wet field	3-6 cm
Cost of machine	Rs. 1,400.00	Rs. 18,000.0

throughout the study.

Machinery Used Self Propelled Rice Transplanter

A Chinese made self propelled 8-row rice transplanter (Model: 2 ZT-238-8), marketed by M/S V. S. T. Agro Inputs, Banglore, was used (**Fig. 1**). It had fixed 23.80 cm row to row spacing and variable plant to plant spacing of 10, 12 and 14 cm at corresponding operating speeds of 1.57 and 1.94 km/h, respectively. The detailed technical specifications of the transplanter are given in **Table 1**.

Drum Seeder

A drum seeder was used for sowing of sprouted rice in dry bed. Specifications are given in **Table 2**. The 8-row pre-germinated paddy seeder was developed at the Central Rice Research Institute (CRRI), Cuttak, India. The seeder had a perforated drum mounted over the axle of the ground drive wheel, a float, five furrow openers, a frame and a handle. The drum had 8 rows of holes with 7 holes in each row.

Fig. 1 Rice seeding in wet bed by drum seeder

Fig. 2 Rice seeding in the dry bed by seed drill

Fig. 3 Direct seeded rice crop in dry bed

Fig. 4 Mate type seedling growing for self-propelled rice transplanter

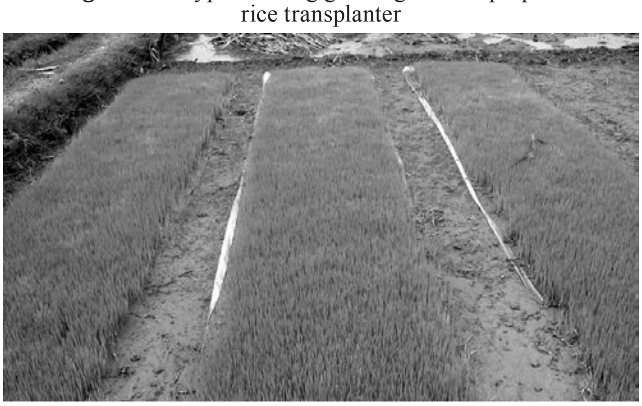

Fig. 5 Operation of self-propelled rice transplanter in the field

It had four drums 30 cm diameter and 30 cm long with circular holes on the periphery 3 cm apart and 20 cm lateral distance. The rice seed from each drum dropped in rows 20 cm apart with in row spacing of 2-3 cm. The drum seeder was half-filled with pre-germinated paddy seeds which dropped through the holes of the drum. It was pulled by two labours in a wet field.

Direct Seeded Rice

The direct seeded rice was sown with a 9-row fluted roller type tractor drawn zero till drill (**Fig. 2**) that was made by National Agro Machineries, Ludhiana. The fluted roller type metering device was used for direct seeding of rice in a dry bed. The seed rate was maintained at 55-70 kg/ha by changing the length of the fluted roller as required by the crop. Row spacing was adjusted at 20 cm (**Table 2**).

Crop Management

The fertilizers for hybrid rice were 150 kg N/ ha, 60 kg P/ha, 60 kg K/ha and 5.5 kg Zn/ha. P, K and Zn. N was applied in four splits (1/4 basal dressing, 1/4 at tillering, 1/4 at active tillering and 1/4 at panicle initiation). Two sprays of $FeSO_4$ at 0.2 % solution 30 and 40 days after planting were given in direct seeding and drum seeding to correct iron deficiency. One hundred twenty kg N/ha were applied to wheat and 60 kg P/ha and 60 kg K/ha were applied as basal with N applied to wheat in these splits (1/2 basal dressing, 1/4 at first irrigation, 1/4 at ear emergence). In hybrid rice, to control weeds, pendimethalin 35 % at 1.25 kg a.i. in 800 liters of water was sprayed at 1-4 days after sowing in direct seeding (dry bed) and for drum seeding (wet bed) butachlor was applied at 1.5 kg a.i./ha at 3 days after transplanting. Thereafter, one hand weeding was done at 30 days after sowing. In wheat, isoproturon at 1.25 kg a.i./ha in 600 liters of water was applied after 30 days of sowing to control the Phalaris minor for providing weed free environment to these crops.

Water Measurement

The direct seeded rice was kept moist during the first week to ensure proper germination and water was not allowed to accumulate to avoid seed rotting. In the drum seeded rice, water was applied before sowing of seed to wet the seed bed. Thereafter, irrigations were applied at 3 day intervals in both treatments. In mechanical transplanting (puddled), manual transplanting (puddled) and mechanical transplanting (puddled) rice, the continuous ponding of water was kept for the first 15 days for better crop establishment. The subsequent irrigations were given 2 days after ponded water infiltrated into soil. The last irrigation to transplanted rice crop was applied 15 days before harvesting. The measurement of irrigation water was done by Parshall flume. The water productivity was computed by dividing the economic yield (kg/ha) with quantity of irrigation water applied. Since 1 m^3 was equal to 1,000 litres and 100 cm water applied was equal to 10,000 m^3 of water in 1 ha:

$$\text{Water productivity (kg/m}^3\text{)} = \frac{\text{Grain yield (kg/ha)}}{\text{Irrigation water applied (m}^3\text{/ha)}}$$

Irrigation water applied (m^3/ha)

Table 3 Energy conversion factors as adopted/advised

Particulars	Units	Equivalent energy (MJ)
Human Power		
a) Adults man	Man-hour	1.96
b) Woman	Woman-hour	1.57
Tractor	hour	332.0
Diesel	liter	56.31
Chemical Fertilizers		
i) Nitrogen (N)	kg	60.60
iii) Phosphorus (P)	kg	11.10
iii) Potash (K)	kg	6.70
Plant protection		
a) Superior chemical (Granular)	kg	120
b) Inferior chemical	kg	10
c) Liquid chemical	ml	0.102
Farm Yard Manure		
Crop Produce (grain)	kg (dry mass)	0.30
i) Rice	kg	14.70
ii) Wheat	kg	15.70

Source: Gopalan et al., (1978) and Binning et al., (1983)

Table 4 The field performance parameters of the self propelled rice transplanter

Parameter	Value
Hill spacing, mm	120
Row spacing, mm	235
Depth of transplanting, mm	30-50
Number of hills, m^2	33-35
Number of seedling/hill	3-5
Fuel consumption, l/h	0.45
Missing hills, %	3-4
Floating hills, %	1.5
Field capacity, ha/h	0.74
Cost of operation, Rs/ha	1,150
Energy requirement, MJ/ha	250

Table 5 Performance parameters of drum seeder and zero till drill for seeding of rice

Parameter	Drum seeder	Zero-till drill
Average length of plumule, mm	2-3	-
Field capacity, ha/h	0.15	0.45
Field efficiency, %	50	70
No of seeds /hill	2-3	Continuous flow
Row spacing, mm	20	20
Hill to hill spacing, mm	10	-
Fuel consumption, l/ha	-	5.6
Cost of operation	Rs. 370 / ha	Rs. 480 / ha
Energy requirement, MJ/ha	52	490
Seed rate	60 kg/ha	55-70 kg/ha

was calculated by multiplying the total depth of water applied through irrigation to the area irrigated.

Energy Estimation

The energy inputs were calculated after multiplying an energy conversion factor to all inputs in the form of the labour, diesel, seed, chemical fertilizer and plant protection (insecticides/pesticides/herbicides) used in all different operations (**Table 3**). The different field operations performed for completion of each activity in the experiment were measured in terms of time taken for human, machinery and fuel consumption and expressed as energy input in mega joules (MJ). The output energy was also estimated in terms of energy output (MJ) using as grain yield under different crops by multiplying an energy conversion factor.

Statistical Analysis

The data were subjected to analysis of variance as per the procedure given by Little and Hills (1978), and treatment means were compared using critical difference (CD) defined as least significant difference beyond which all the treatment differences were statistically significant as CD = $(\sqrt{2VE}\ ^{r-1})\ t^{5\,\%}$ where VE is the error variance, r the number of replications of the factor for which CD is calculated, $t^{5\,\%}$ the table value of t at 5 % level of significance at the error degrees of freedom.

Results and Discussion

Performance of Machines

Self Propelled Rice Transplanter

The performance of the rice transplanter was highly dependent on the puddled soil condition and seedling density (seedlings/cm^2) in the mat (**Table 4**). The average number of hills/m^2 was 33-35. The field capacity of transplanter was 0.74 ha/h and diesel consumption was 2.9l/ha. The row spacing and hill to hill spacing was 12 and 23.5 cm and average number of seedlings/hill was 3-5 and depth of planting was 3-5 cm. The missing hills were 3-4 %. This was dependent on the seedling density in the mat. The floating hills were about 1-1.5 % due to a higher puddling level and less sedimentation period (Chaudhary et al., 2003). The uniform growth of crop was due to uniform depth of placement of seedlings at uniform spacing with equal number of seedlings per hill that resulted in better yield for the mechanically transplanted field than the manual transplanted field. The cost of operation was Rs 1,150/ha. The energy requirement of this machinery was 250 MJ/ha.

Drum Seeder

The performance of the drum seeder was evaluated by the direct seeded rice that sprouted under wet bed in unpuddled condition (**Table 5**). The rate of pre-germinated rice seeds was 40 kg/ha. The field capacity of the drum seeder was very low at 0.13 ha/h. Two to three seeds were dropped in a hill at a spacing of 3-5 cm with row spacing 20 cm. The cost of operation was Rs 300/ha. The energy requirement was estimated as 52 MJ/ha.

Direct Seeded Rice

The performance parameters of zero-till drilling of rice saved about 65 to 80 percent time, labour, fuel, cost and energy saving as compared to conventional methods of rice. The field capacity of direct seeded rice was 0.45 ha/h and diesel consumption was 5.6 l/ha (**Table 5**). The row spacing was 20 cm with continuous flow of seed in the furrow and the depth of seeding was 3-5 cm. The uniform growth of the crop was due to uniform germination of seedlings. The cost of operation was Rs

Table 6 Grain yield (t /ha) of rice and wheat as influenced by different methods of rice planting method

	2003-04		2004-05		2005-06		Mean	
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)-dry bed	7.84	5.62	8.53	5.76	8.55	5.72	8.31	5.70
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)-wet bed	8.11	5.50	8.71	5.63	8.74	5.60	8.52	5.58
T_3 : Mechanical transplanting (2 harrow + 1 planking + 2 passes of puddler)- puddled	7.75	4.74	8.45	4.90	8.46	4.86	8.22	4.83
T_4 : Mechanical transplanting (2 harrow + 2 planking)-unpuddled	7.33	5.48	7.73	5.59	7.86	5.55	7.64	5.54
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	7.46	4.85	7.84	5.06	7.89	5.02	7.73	4.98
CD (P = 0.05)	0.38	0.17	0.19	0.25	0.41	0.24	-	-

480/ha. The energy requirement of this machine was 490 MJ/ha. The direct and drum seeded rice crop matured at about 8-10 days before as compared to transplanted rice.

Crop Yield and Attributes

The grain yield of rice was significantly influenced by different machinery effects on rice crop establishment (**Table 6**). The pooled yield of rice was higher (8.52 t/ha) with drum seeding (wet bed) followed by direct seeding (8.31 t/ha) in (dry bed) and mechanical transplanting (8.22 t/ha) in (puddled) compared to manual transplanting (7.73 t/ha) in (puddled) and mechanical transplanting (7.64 t/ha) in unpuddled conditions. The mean yield of rice for three years was higher by 10.22 % in drum seeding (wet bed) followed by 6.88 % in direct seeding (dry bed) over other methods of rice crop establishment. This was mainly attributable to relatively greater compaction of puddled soil under manual and mechanical transplanting (puddled). Higher values of yield contributing characters (**Table 7**) such as number of panicles/m^2, number of grains/panicle and 1,000 grain weight under drum seeding (wet bed) in rice while number of ears/m^2, number of grain/ear and 1,000 grain weight in wheat were recorded under direct seeding (dry bed) in succeeding crops.

Energy Dynamics in Systems

System wise energy analysis (**Table 8**) indicated that the highest

Table 7 Yield attributing character of rice and wheat as influenced by rice planting methods (pooled data of 3 years)

Treatments	Rice			Wheat		
	No. of panicle/ m^2	No. of grains / panicle	1,000-grain weight (g)	No. of ears /m^2	No. of grains / ear	1,000-grain weight (g)
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)- dry bed	363	132	27.1	295	49.72	37.82
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)- wet bed	383	141	27.7	285	48.14	37.59
T_3 : Mechanical transplanting (2 harrow + 1 planking + 2 passes of puddler)- puddled	354	131	26.7	272	41.40	36.95
T_4 : Mechanical transplanting (2 harrow + 2 planking)- unpuddled	300	113	26.3	283	46.54	37.37
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	333	122	26.5	276	41.78	37.06
CD (P = 0.05)	11	9	0.9	4	0.91	0.24

Table 8 Energy dynamics (MJ/ha) of rice-wheat cropping system as influenced by rice planting methods (pooled data of 3 years)

Treatments	Total input energy	Total output energy	Net return energy	Output-input ratio
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)- dry bed	42,279	211,350	169,070	5.0
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)- wet bed	41,872	212,798	170,926	5.1
T_3 : Mechanical transplanting (2 harrow + 1 planking + 2 passes of puddler)- puddled	42,873	200,215	157,343	4.7
T_4 : Mechanical transplanting (2 harrow + 2 planking)- unpuddled	41,172	209,091	167,919	5.1
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	43,375	193,916	150,542	4.5

input energy was (43,375 MJ/ha) consumed in manually transplanted (puddled) followed by (42,873 MJ/ha) in mechanically transplanted (puddled) and lowest was 41,172 and 41,182 MJ/ha in mechanically transplanted (unpuddled) and drum seeded, respectively, in rice-wheat system. The fertilizer consumed highest input energy, about 42 to 45 % of total input energy use, followed by 21 to 25 % in irrigation, 11 to 18 % in land preparation, 9 to 10 % in seed and sowing and 2 to 3 % in interculture/weeding in the rice-wheat system. However, the output energy was highest in drum seeded (212,798 MJ/ha), closely followed by direct seeded (211,350 MJ/ha) and the lowest was 193,916 MJ/ha in manually transplanted (puddled). The net return energy of the system was high in drum seeded (170,926 MJ/ha) followed by direct seeded (169,070 MJ/ha) and lowest was 150,542 MJ/ha in manually transplanted (puddled).

The input energy for the manually transplanted was higher due to higher use of inputs as in tillage operations and the sowing operation as compared to direct seeded and drum seeded rice in which the tillage operation was minimum where energy consumed by diesel was much less (*Chaudhary et al.*, 2006). The drum seeded rice required 3.6 % less input energy and gave 8.9 % higher output energy, whereas, direct seeded required 2.6 % less input and gave 8.2 % higher output energy as compared to manually transplanted (puddled). The output energy and net return energy was higher in drum seeded and direct seeded, due to its higher grain yield that resulted from good crop establishment in minimum tillage and unpuddled field.

Water productivity

The direct seeded (dry bed) and drum-seeding (wet bed-unpuddled) have identified one possibility for saving irrigation water by 13 to 19 % when compared to manual transplanting (puddled) (**Table 9**). The saving of water was due to rice crop established in the unpuddled field. Secondly, the crop of direct seeded and drum seeded matured 8-10 days earlier than transplanted crop. The water productivity in direct seeded varied from 0.664 to 0.742 and drum seeded varied from 0.676 to 0.738 kg grain/m^3, whereas, it varied from 0.587 to 0.660, 0.583 to 0.622 and 0.524 to 0.577 kg grain/ m^3 in mechanical transplanting (puddled), manual transplanting (puddled) and mechanical transplanting (unpuddled), respectively.

Conclusions

The present study indicated that drum seeding (wet bed) resulted in the maximum grain yield (8.52 t/ha) of hybrid rice for better crop growth and its establishment while direct seeding (dry bed) adopted in preceding rice crop produced greater yield of the subsequent wheat crop. The substitution of wheat in unpuddled soil drum (wet bed) and direct seeding (dry bed) not only produced relatively higher economic yield but also used less energy. The output energy was highest in drum seeded (212,798 MJ/ha) closely followed by direct seeded (211,350 MJ/ha). The lowest was 193,916 MJ/ha in manually transplanted (puddled). The net return energy of the system was high in drum seeded (170,926 MJ/ha) followed by direct seeded (169,070 MJ/ha) and lowest of 150,542 MJ/ha in manually transplanted (puddled). In addition to this, the direct seeded (dry bed) and drum-seeding (wet bed-unpuddled)

Table 9 Water Productivity of rice as influenced by crop establishment practices and tillage levels

Treatments	Irrigation water applied (cm)			Water productivity (kg grain m^{-3} of irrigation water)		
	2003-04	2004-05	2005-06	2003-04	2004-05	2005-06
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)- dry bed	118	115	123	0.664	0.742	0.695
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)- wet bed	120	118	126	0.676	0.738	0.694
T_3 : Mechanical transplanting (2 harrow + 1 planking + 2 passes of puddler)- puddled	132	128	138	0.587	0.660	0.613
T_4 : Mechanical transplanting (2 harrow + 2 planking)- unpuddled	140	134	142	0.524	0.577	0.554
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	128	126	135	0.583	0.622	0.584
CD (P = 0.05)	-	-	-	0.080	0.086	0.083

showed a possible saving of irrigation water by 13 to 19 % when compared to manual transplanting (puddled).

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Status of Post Harvest Technology of Agricultural Crops in Sri Lanka

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Abstract

Sri Lankan economy is traditionally dominated by agriculture. The main food crops cultivated in Sri Lanka can be broadly categorized as perishables and non-perishables. The former include fruits and vegetables and the latter consists of grains, field crops and spice crops. Due to use of inadequate and poor post production techniques serious quantitative and qualitative losses occur in these crops. The post harvest losses range between 10-20 % for durables and 30-40 % for perishables. There is a great need to adopt and develop simple technologies for loss prevention and value addition at catchments level.

Introduction

Sri Lanka is an island in the Indian Ocean, situated between 6o and 10o North of the equator. Its land area of 6.46 million ha is divided into wet, intermediate and dry zone, based on rainfall that is received during two monsoons, i.e. Northeast from October to March (Maha season) and Southwest, from April to September (Yala season). The land area under each zone is 1.54, 0.85 and 4.07 million ha, respectively.

Agriculture is the predominant sector of the economy of Sri Lanka as this contributes 17.2 percent to the gross domestic production (Annon, 2007). The agriculture sector not only creates a large number of employment opportunities but also provides a source of livelihood for the majority of the people. The investment scenario in the agriculture sector may have phenomenal impact on the economic situation of the people. The present population of the country is 19.5 million (Annon, 2007). According to the FAO statistics, the projected population for the year 2025 is 21.5 million (www.fao.org visited on 2008.08.08). Therefore, feeding the population will surely be one of the major challenges that merit urgent attention. A considerable increase in agricultural productivity either through sustainable agricultural growth or through rapid growth in income will be essential to meet the coming challenges of worsening poverty, feeding the growing population and protecting the environment. Effort to increase food production is one aspect of the solution, but equally important is the issue of post harvest technology that has not received adequate attention so far. The classical domain of the investment in the agriculture sector has undermined the role of post harvest technology. The post harvest system should not be considered in isolation but as an integral part of the agrarian system where farm produce is properly harvested, handled, graded, packed, stored, transported, processed and marketed.

Production and Marketing

Agriculture has been Sri Lanka's main livelihood from ancient times and today nearly 90 percent of the poor live in the rural agricultural economy (Annon, 2008). Among the many food crops cultivated in Sri Lanka, rice constitutes the main crop. Rice is the staple food of Sri Lankans and it is the livelihood of more than 800,000 farm families. More than 30 % of the total labor force is directly or indirectly involved in the rice sector. Apart from rice, the other major income generating field crops cultivated in Sri Lanka are maize, sorghum, green gram, black gram, cowpea, ground nut, sesame, onion, chili and potato.

Most high value crops such as chili, onions and potatoes are grown very intensively, at times under irrigated conditions, while the rest are grown in an ad-hoc manner in home gardens or in chena lands under rain fed conditions. Although the individual land holdings cultivated with these crops are small, a large number of families are engaged in their cultivation and they make a substantial contribution to employment and gross domestic production. **Table 1** shows the annual extent cultivated and production of major seasonal crops from 2003 to 2007 in Sri Lanka.

A variety of fruits and vegetables are also cultivated in Sri Lanka. Vegetable cultivation can be broadly classified into low country vegetables and upcountry vegetables. Major low country vegetables are brinjals, ladies finger, pumpkin, tomato, cucumber and drumsticks and are generally cultivated under rain fed conditions on small plots of land or in home gardens using little fertilizer or pesticides except in paddy fields during Yala season under irrigated conditions. Harvesting is on a seasonal basis. Upcountry vegetables are leeks, beans, cabbage, carrot, beet root, cauliflower, lettuce and are cultivated more intensively under irrigated conditions at high altitudes and most of these vegetables are temperate varieties. The cultivation is staggered and harvesting is carried out through out the year. Commercial cultivation of vegetables with heavy capital investment has been started recently and is becoming increasingly popular due to higher returns. **Table 2** shows the annual extent of cultivation and production of major up country and low country vegetables from 2001 to 2005 in Sri Lanka.

Sri Lanka does not have well managed fruit orchards as in other countries. The commercial cultivation is reported only for few fruits such as banana, pineapple, papaya, passion fruit and rambutan. Other fruit varieties such as mango, wood apple, guava, avocado are supplied mainly from home gardens. Moreover, a considerable proportion of banana, papaya and rambutan come from home gardens as well. Other fruit varieties such as mango, wood apple, guava and avocado are, also, supplied mainly from home gardens. Moreover, a considerable proportion of supply of banana, papaya and rambutan are come from home gardens as well. **Table 3** shows the annual extent of cultivation and production of some major fruits from 2001 to 2005.

The demand for local fruits such as banana, mango, pineapple and papaya are met mainly through local production. Only negligible quantity of these fruits has been imported to meet specific requirements of tourist hotels or to meet the requirements of processing factories. However, the local demand for certain fruits such as apples, oranges, grapes, pears and dates is met through imports.

Marketing Channel for Agricultural Produce

The marketing of paddy and other grains in Sri Lanka is mostly practiced through four major channels. Middle level collectors buy directly from the farmer and sell to millers. Grain processors or millers buy grains from farmers directly or middle level collectors. Wholesalers buy rice and other grains products

Table 1 Annual Cultivated Extent and Production of Major Seasonal Crops in Sri Lanka

Crop	Extent Cultivated (Hectares' 000)					Production (MT' 000,000)				
	2003	2004	2005	2006	2007	2003	2004	2005	2006	2007
Paddy	911	719	915	900	713	3,067	2,628	3,246	3,341	3,131
Maize	27.06	23.43	28.41	32	34.19	29.65	35.20	41.80	47.53	56.44
Finger millet	7.36	5.12	6.21	5.91	5.41	5.27	4.67	6.45	6.29	5.46
Green gram	12.01	8.61	9.64	8.7	8.76	10.61	7.81	9.00	7.98	8.52
Cowpea	13.84	9.66	11.36	10.65	10.63	12.90	9.16	11.18	10.12	10.85
Black gram	7.19	4.74	6.21	6.80	6.82	5.94	4.96	6.92	7.47	7.75
Soya bean	2.55	1.30	3.08	3.07	2.86	2.96	1.89	4.99	5.18	4.80
Gingerly	8.81	6.99	9.65	9.34	9.26	5.49	4.35	6.16	5.97	6.30
Ground nuts	11.38	9.98	10.92	11.66	10.42	6.58	7.93	9.04	9.82	9.84
Red onion	4.90	4.39	5.79	6.23	5.61	35.51	39.64	53.73	60.76	57.04
Big onion	2.77	3.08	4.56	6.81	6.99	32.31	37.51	55.55	73.61	92.16
Chilies (Green)	15.92	13.75	17.31	14.89	14.09	46.19	40.48	52.87	52.90	48.70
Ginger	1.25	1.23	1.35	1.36	1.53	4.84	5.69	6.70	6.76	8.27
Potatoes	6.31	5.49	5.61	5.48	5.33	71.75	81.27	79.45	78.49	77.39
Sweet Potatoes	7.57	6.42	6.62	6.65	6.53	44.05	39.72	41.18	41.62	40.16
Manioc	26.28	23.14	23.45	23.56	22.56	228.84	220.58	223.21	226.08	219.94

Source: www.statistics.gov.lk, visited on 2008.08.08

from millers directly and sell to retailers. The retailers sell rice and other grain products to consumers (Dissanayake, 2005).

There are different marketing channels for fruits, vegetables and some other seasonal cops. At present, a considerable portion of fruits and vegetables is brought to the regional wholesale markets and from there the commodities are directly supplied to the consuming areas. However, very recently, several efficient marketing channels were established directly between the farmers or producers and the super market network without going through either the collector or the wholeseller. Further, some super market networks established their own collecting centers in major vegetable producing areas with improved handling, packaging and cold storage facilities. There was a change observed during recent past after establishing the regional wholesale markets known as Dedicated Economic Centers in 1999 in Embilipitiya, Meegoda, Keppatipola, Dambulla, and Thambuttegama. (Annon, 2008).

Post Harvest Operations

Post Harvest Practices of Grain

Harvesting

Presently, a majority of farmers in Sri Lanka harvest paddy and other grains manually with a sickle. This is a very time and labor consuming operation. On an average, it takes from 150 to 180 man-hours to harvest one hectare of the paddy crop. During the recent years, attempts have been made to introduce power-operated harvesting machines to farmers. **Table 4** shows percentage mechanization in harvesting, threshing and combine harvesting.

Threshing and Cleaning

Various methods of threshing grains have evolved through the years, ranging from manual threshing to more sophisticated engine–driven ones. The existing threshing practices in Sri Lanka include buffalo threshing, tractor threshing and mechanical threshing. In the major rice producing areas of Sri Lanka nearly 80 percent of farmers use four-wheel tractors for threshing of paddy and other grains. At the same time, the use of mechanical threshers has become popular among farmers in major rice producing areas recently and in areas where the individuals land holdings are small.

Presently, threshed paddy and other grains are cleaned by winnowing. Winnowing of threshed paddy and other grains with natural wind and by aspiration using a fan coupled to two wheel tractors or four-wheel tractors are common in the country. Some mechanical threshers are equipped with a cleaning and

Table 4 Harvest and Threshing Mechanization in Sri Lanka (Percentage)

Operation	Value %
Harvesting	15
Threshing	60
Combine Harvesting	5

Source: http://www.doasl.gov.lk, visited on 2008.08.08

Table 2 Annual extent cultivated and production of some major up country and low country vegetables

Crop	Extent Cultivated (Hectares)					Production (MT)				
	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005
Beans	6,353	6,556	6,291	7,469	7,715	30,891	32,648	31,687	39,603	40,790
Cabbage	3,936	3,633	3,718	3,869	4,099	53,935	49,339	52,222	60,505	63,902
Carrot	2,554	2,543	2,486	2,881	3,091	28,424	28,160	27,210	34,345	36,930
Leeks	1,665	1,594	1,537	1,821	1,762	24,189	23,152	22,420	29,717	28,451
Beet-root	1,880	1,803	1,721	1,865	2,114	17,736	16,500	15,574	19,643	22,371
Tomato	5,328	5,413	5,936	5,981	6,213	40,378	41,238	44,974	53,768	56,894
Brinjals	9,413	9,905	10,629	9,325	9,787	67,409	70,634	74,469	80,377	83,640
Red pumpkin	6,427	6,622	7,228	6,543	8,199	58,529	59,578	63,830	67,964	79,581
Ladies fingers	6,707	6,952	6,857	5,896	6,744	35,905	37,665	36,786	36,352	41,172
Cucumber	2,355	2,643	3,152	2,674	3,153	18,451	20,994	23,383	22,901	26,829

Source: www.harti.gov.lk, visited on 2008.08.08

Table 3 Annual extent cultivated and production of some major fruits

Crop	Extent Cultivated (Hectares)					Production 000' Nos (*000' Bunches)				
	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005
Banana*	45,809	47,850	49,677	50,376	51,147	30,575	31,719	32,997	33,750	3,4083
Papaya	3,093	3,564	4,653	5,013	4,941	22,632	26,310	29,641	31,036	30,390
Pineapple	4,832	4,800	4,825	5,188	5,257	42,594	42,432	40,716	48,065	48,721
Mango	25,728	27,071	28,627	26,330	27,200	458,987	487,228	500,577	459,552	464,125

Source: www.harti.gov.lk , visited on 2008.08.08

separating mechanism.

Drying

Drying is done on-farm and off-farm. It is accomplished by either field drying, sun drying, or mechanical drying. The method used depends on the scale of operation, degree of awareness on post harvest technology and socio-economic conditions of farmers. A majority of farmers and traders/millers rely on sun drying that has been the main method of drying of paddy in Sri Lanka. Mechanical drying is being practiced by only a few traders/millers.

Storage

Storage occurs at two levels, on-farm and commercial. The later is what traders and millers buy from the farmers and are stored in sacks, inside warehouses. Farmers store their grains in sacks inside their homes. The farmers also use some other types of improved traditional storage structures such as clay bissa and gunny bissa (*Fernando et al*., 1988). Even though in traditional villages, indigenous bulk storage structures are used for on-farm storage, in settlement schemes farmers store their paddy in bags. In the case of bag storage, farmers store paddy in jute bags or polypropylene bags in substantial quantities for a period of 1 to 12 months. They generally use part of their houses as a store and it is very seldom that separate buildings are used.

Storage of grain at the commercial level is mainly done in bags in a warehouse with different capacities and is at a considerably developed stage where scientific storage practices are adopted to keep losses at minimum. The paddy marketing board of Sri Lanka had a capacity of storing 356,000 tons of paddy in their warehouses with different capacities, viz. 9,000 tons (*Araullo et al*., 1985). The paddy grain is stored at an average moisture content of 13-14 %.

Milling

The rice processing industry is the largest agro-based industry in the country, turning more value of product than any other industry. A survey conducted by the Institute of Post Harvest Technology, Sri Lanka in 2001, identified two systems of rice milling in the country, custom and commercial. The total number of rice mills in Sri Lanka is nearly 7,000 and out of which 77 % are custom and 23 % are commercial. The former mills are those that mill rice belonging to farmers for a custom fee and the later are those that mill paddy purchased from growers for sale in the open market. The total milling capacity in the country is approximately 2,700 metric tons per hour, of which 60 % is in custom mills and the rest in commercial mills. The survey on rice milling also revealed that 100 % of the custom milling capacity and 95 % of the commercial milling capacity is owned by the private sector (Annon, 2002).

Post Harvest Practices of Fruits and Vegetables

Harvesting

Serious quantitative post harvest losses and quality deterioration of fruits and vegetables occur due to adoption of improper post harvest practices at the producer level. Such practices are harvesting at incorrect stage of maturity and adoption of improper handling and packaging methods. At present, harvesting is carried out manually. However, use of properly designed harvesting tools is practiced by some farmers, which not only prevents undue mechanical damage but, also, appreciably reduces the cost of production of tree fruits.

Washing and Cleaning

After removal of rejects, the fruit is cleaned to remove most of the dirt from the field such as dust, plant debris, soil, latex, insects and pesticides. This is achieved by washing or brushing/wiping or both. Vegetables such as leeks, carrots, radish and beetroot are usually washed after harvesting to remove all sand, stones, soil clods and plant debris. For this purpose, a majority of farmers in the up-country area use water streams and rivers near their farm lands that flow throughout the year. As farmers use more fertilizers and insecticides, water available in streams and rivers become polluted, which may results in contaminating the vegetables with bacteria and pesticide residues (*Abeykoon et al*., 2008).

Sorting and Grading

In Sri Lanka, a majority of farmers market their produce without sorting and grading. At present, sorting and grading are carried out manually to some extent by wholesale and retail traders, especially at the super market level. No mechanical grading and sorting facilities are available elsewhere.

Handling and Transportation

A major part of the loss occurs during transportation from farm gate to collection centers and then to village fair or wholesale markets and subsequently retail outlets. Vegetables are often packed tightly by forcing in polypropylene sacks. These sacks do not provide suffi-

Table 5 Post harvest losses in essential food commodities (Percentage by weight)

Crop %	Loss %	Crop %	Loss %
Cereals:		Oil crops:	
Rice	15	Ground nut	08
Maize	07	Sesame	10
Legumes:		Fruits:	
Green gram	15	Banana	20
Black gram	15	Mango	46
Soya bean	08	Pineapple	18
Cow pea	15	Passion fruit	20
Pigeon pea	15	Papaw	48
Field crops:		Lime	20
Red onion	30	Vege-tables	
Big onion	30	Okra	16
Chilies	10	Cabbage	41
Potato	30	Leeks	38

Source: Annon, 2003

cient ventilation for the produce and results in temperature build up that accelerate both toughening and senescence. The fruits and vegetables packed in poly-sacks are usually kept near roadside until the collectors come to pick them up. This provides the possibilities to exposure of fresh produce to sun or rain. Rough handling and loading take place during transportation. Because of the high transportation cost, the collector or wholeseller generally tends to transport the maximum amount possible. Packaging used by traders, does not accommodate or compensate for bad road surfaces and high ambient temperature and humidity conditions that prevail during the extended period of transportation that results in a rapid deterioration of quality. Thus, produce is often bruised, infested by post harvest pathogens and is not of optimum quality on reaching distribution points.

Processing of Fruits and Vegetables

At present, most of the farmers market their produce in the unprocessed form. Some viable value adding techniques that have been introduced for perishable and non-perishable crops in Sri Lanka are: rice processing, pulse (legume) processing, grain flour milling, manufacture of weaning foods, drying/dehydration of fruits, manufacture of sauces, pickles and jams and packaging. These are operating as cottage level, small and medium scale food processing units with a few large scale food processing industries. However, no data are available for the food processing industries.

Post Harvest Losses

The studies have shown that, due to use of improper post production techniques, serious quantitative and qualitative losses occur in these crops. Gains in yields are often offset by post harvest losses from the stage of harvesting until the produce reaches to the final consumer or processor. The post harvest losses of durables range between 10-20 % and 30-40 % for perishables (Anon, 2001). The total value of these losses has been estimated to be US$ 113-123 million, out of which fruits and vegetables contribute more than US$ 76 million (Anon, 2001). The quantitative losses occurring in essential food commodities during post harvest handling, storage and processing in Sri Lanka are given in **Table 5**. In addition, a field survey was conducted by the IPHT in 2001 in 15 districts, to represent the entire country, to assess the post harvest losses in different unit operations for economically important perishable and non-perishable crops. **Table 6** illustrates the losses for major crops under different unit operations (Annon 2003).

Major Causes for Post Harvest Losses

A huge amount of loss occurs in the post harvest chain of operations of agricultural produce. Several factors contribute to this dismal plight such as: lack of appropriate post harvest handling equipment and processing facilities, storage pest infestation, diseases, mycotoxin contamination after harvest and biological deteriorations due to unscientific storage practices, lack of workable standards for proper inspection and grading system, low adoption of improved post harvest facilities as influenced by socio-cultural constraints, beliefs and viability. Post harvest losses of agricultural produce also results from spillage, inefficient retrieval and other processing factors such as operator skills and inefficient machines.

Prevention of Post Harvest Losses

The Institute of Post Harvest Technology (IPHT) established in 2000 at Colombo under the Ministry of Agriculture has implemented the following national level programs for post harvest loss prevention and development of agro-processing industries to enhance agricultural productivity and farm incomes.

Establishment of Rice Processing Villages:

Establishment of rice processing villages in major rice producing areas in the country was started in 2006. If rural farmers engaged

Table 6 Post harvest losses during different unit operations (Percentage by weight)

Crop	Paddy %	Maize %	Pulses %	Oil Seeds %	Dried Chili %	Vegetables %	Fruits %	Chili-Green %
Harvesting	2.98	7.32	1.87	6.77	9.03	8.89	8.76	9.03
Collecting	-	-	-	-	-	2.22	1.76	2.56
Drying	1.65	2.78	2.70	3.50	2.67	-	-	-
Threshing/Cleaning	4.34	0.91	2.32	3.66	-	-	-	-
Storage	3.86	2.35	2.22	3.42	10.36	-	-	-
Transport	1.02	-	-	-	-	12.6	5.11	5.47
Selling	-	-	-	-	-	12.13	11.67	3.45
Milling	1.67	-	-	-	-	-	-	-
Total	15.31	13.36	9.11	17.35	22.06	35.81	27.32	20.51

Source: Annon, 2003

themselves in rice processing, they could increase the market value of their produce and thereby significantly increase their income. At the same time, they could create self-employment among the rural farming sector and reduce post harvest losses caused by storage and transportation.

During the 2006, forty nine rice processing villages were initiated in Anuradhapura, Pollonaruwa, Ampara, Kurunegala, Badulla, Monaragala and Kandy districts consisting of 10 to 20 farm families in each village. The members of rice processing villages acquired parboiling and milling facilities through concessionary credit obtained from development banks in the area. The parboiling capacity of each family is 150-200 kg per day. At present, the members of rice processing villages produce high quality rice using the technologies developed by the IPHT and sell in the rural sector market as well as in the urban market. Each family generates a net income of approximately US$ 60 per month in project areas by selling rice instead of paddy (Annon, 2007).

Establishment of Fruit and Vegetable Processing Villages:

Next to paddy, the fruit and vegetable sub sector is the most prominent in the agriculture sector as these crops are grown through out the country that include large numbers of farmers. Realizing the importance of adopting improved technologies in fruit and vegetable production and initiating rural level micro enterprises, using value added technologies, the Institute of Post Harvest Technology launched a programme to establish fruit/vegetable processing villages in major fruit and vegetable producing areas of the country in 2006.

Twenty two such villages were established in Anuradhapura, Pollonanruwa, Kurunegala, Ampara, Kandy and Badulla districts consisting of 10-15 farm families in each village. The members of fruit/vegetable processing villages acquired necessary equipment and facilities to establish dehydration and processing units through credit obtained from local development Banks and financial assistance provided by NGO. The necessary technologies were provided by the IPHT (Annon, 2007).

At present the members of theses villages adopt improved post harvest technologies such as maturity indices, harvesting equipment, grading and sorting techniques, plastic crates for handling and transportation and also produce value added processed products for the rural sector as well as urban market.

Modernizations of Rice Mills:

The Institute of Post Harvest Technology started in 2001 and continued the rice mill modernization programme to improve the processing techniques of existing rice mills in the country. Identification of deficiencies of the techniques presently adopted in the process line of the mills was made. This included submission of reports for each rice mill and recommendation of modifications required to improve rice quality and increase rice out put, along with provision of process layout plans, conducting a series of training programmes for selected millers and development of effective marketing channels for export quality rice. Continuous monitoring of rice mill modernized under this project was carried out under this project.

During the period under review, under this programme, 188 rice millers in different parts of the country were trained. The IPHT was able to modernize 59 large/medium commercial rice mills in major rice producing areas of Polonnaruwa, Kurunegala, Hambantota, Ampara, Mahaweli system C and Minipe by including polishers, de-stoners, water jet polishers, rice graders and color sorters in to the existing system. In addition, 62 technical and feasibility reports were provided for the establishment of new rice processing plants and modernization of existing plants (Annon, 2006).

Promoting Packaging Methods and Transportation:

A national level project to distribute plastic crates and to modify transportation vehicles on a subsidized rate is in progress now for the reduction of post harvest losses in fruits and vegetables. The Institute of Post Harvest Technology has introduced plastic crates for packaging of fruits and vegetables during handling and transportation from growers to collectors, wholesalers and retailers at 50 % subsidized rates. The government of Sri Lanka granted US$ 50 million from the national budget to distribute plastic crates among the target groups and to modify the existing transportation vehicles so that they would be suitable for transportation of these perishable commodities. Under this project 50,000 crates have been purchased by those engaged in the chains and are now in operation. This has enabled the supply of good quality produce to the consumer at a cheaper rate while farmers are being given good value for their production.

Enhancing Research Capabilities of Institutions Engaged in Post Harvest Research and Development Activities:

The success of establishing viable post harvest loss prevention and agro-processing technologies in Sri Lanka will depend, to a great extent, on the availability of appropriate technologies that are scale neutral, resource neutral and cost effective. Hence, it becomes a continuous process for local institutions engaged in post harvest research namely, IPHT, National Engineering Research and Development Centre, Department of Agriculture, Industrial Technology Institute and Universities to undertake demand driven applied research to identify, develop and evaluate such technologies. In this context, the government enhances the research capabilities of the national research institutions by strengthening their financial, manpower and material resources.

Conclusions

1. Improved technique and equipment should be introduced for harvesting, threshing, drying, and milling of agricultural crops for minimizing losses. Care should be given for proper operation and maintenance of the machinery and equipment by imparting training to operators.
2. Improved storage techniques and structures should be popularized and introduced at farm and commercial levels.
3. Strict quality control should be observed at the time of procurement.
4. Commercialization of the traditional domestic agriculture is important for sustainable crop production and alleviation of poverty among the rural farming sector.
5. Island wide post harvest loss assessment for grains, fruit, vegetable, spice and other crops should be done by the relevant authorities in Sri Lanka.
6. The government should give more emphasis on infrastructure facilities available for technology adoption like waiving of levy, concession of power tariff and financing for farmers, millers and entrepreneurs.

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Evaluation of Cotton Processing Loss in Modernized Indian Roller Gins

by

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Abstract

The losses in modernized cotton gins mainly occur while processing of cotton. Losses could be either visible or invisible. Large scale trials were conducted to evaluate the processing loss on the first and second cotton picking in a modernized roller gin. Visible loss of 0.56 %, 0.11 % and 0.28 % was found at the pre-cleaner, lint cleaner and cyclones, respectively, for the first cotton picking. Similarly, visible loss of 0.70 %, 0.20 % and 0.50 % was found at the pre-cleaner, lint cleaner and cyclones, respectively, for the second cotton picking. The total processing loss for the first cotton picking was 1.8 %, which consisted of 1.1 % visible and 0.7 % invisible loss. The total processing loss for the second cotton picking was 3.3 %, which consisted of 1.6 % visible and 1.7 % invisible loss. The present study will provide ginners a general guideline about the likely processing loss at different stages of cotton processing in a modernized gin. It will also help minimize the processing loss by adopting the appropriate measures.

Introduction

In India about 70 % of cotton is ginned on double roller gins. Saw gins are also in use in the northern cotton growing part of the country. According to the ICAC report about 15 % of the world cotton is ginned on roller gins. In conventional roller gins, the entire handling of cotton is done manually and the machines are old and outdated resulting in lint quality degradation. The Government of India has launched a Technology Mission on Cotton (MM-IV) especially for the modernization of ginning and pressing factories. Under TMC about 1,000 ginning factories will be modernized. Modernization helps in reducing the contamination in the in cotton. But, with the advent of modernization, ginners felt the problem of increased processing loss while processing the cotton in gins. Hence, ginners think twice before they go ahead with modernization of their gins.

The cotton losses start right from harvesting, transportation, storage, ginning, spinning and, finally, while making into cloth. The losses in gins and mills are mainly due to due to processing cotton and can be called processing loss. Ginning is the first mechanical processing treatment that cotton undergoes before it is converted into usable form. Losses are either visible or invisible or waste generated during the cleaning processes. These losses should be accounted for to make the ginning business more profitable. The processing loss in conventional gins appears to be less but, due to modernization, this problem has become severe. Processing loss in gins beyond a certain level cannot be accepted and it may lead to huge income loss. The ginners are unaware of the amount of likely processing loss they will be incur during ginning. Hence, looking into the problems faced by the cotton ginners, a study was conducted to evaluate the processing loss in modernized gins. Some useful guidelines and recommendations were suggested for the ultimate users to know how to keep this processing loss to a minimum.

Materials and Methods

Experimental trials were conducted to determine the processing loss in a commercial, modernized gin for the first and second cotton picking. The trials were carried out on MECH-1 first picking and LRA-5,166 second picking cotton. Fifty quintals of seed cotton was taken for each trial of first and second picking cotton. Each trial was made in two replications. **Fig. 1** shows the schematic diagram depicting the sequence of machinery used in cotton processing in amodernized gin.

The seed cotton was passed through the pneumatic conveying systems, stone catcher, pre-cleaner, automatic feeding system and then ginned on a double roller gin. The lint was conveyed pneumatically to the lint cleaner and again conveyed pneumatically to the pala house. The lint was then conveyed pneumatically to the press house for final bale pressing. The seed were conveyed from gin house to seed platform by bucket elevator and screw conveyor. All the necessary settings and adjustments were made in all the machinery before the start of the trial. **Fig. 2** shows the flow

Fig. 2 Flow diagram depicting the different stages of processing of cotton in a gin

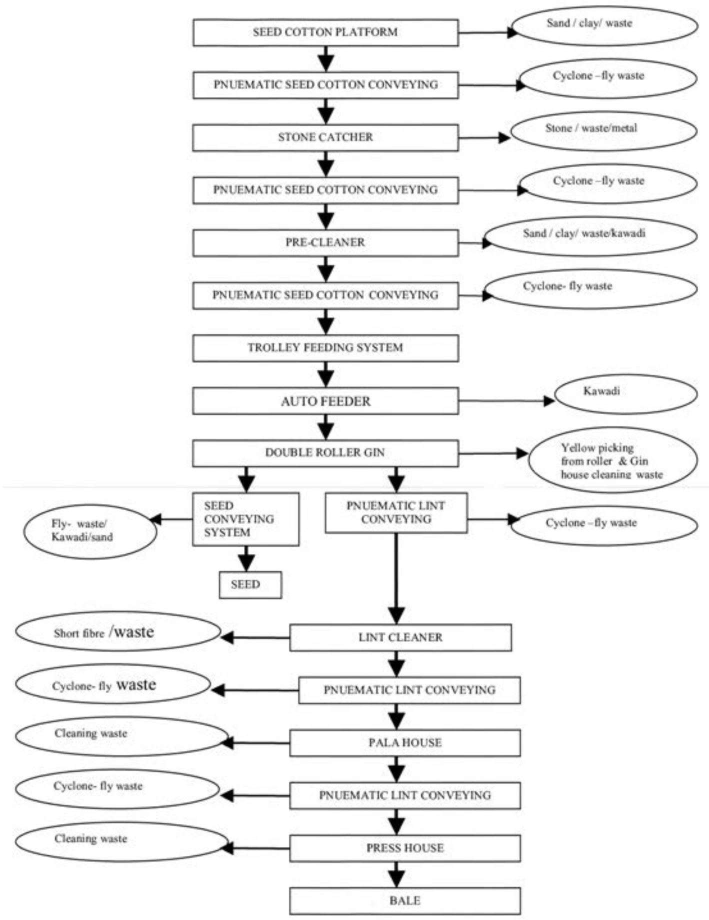
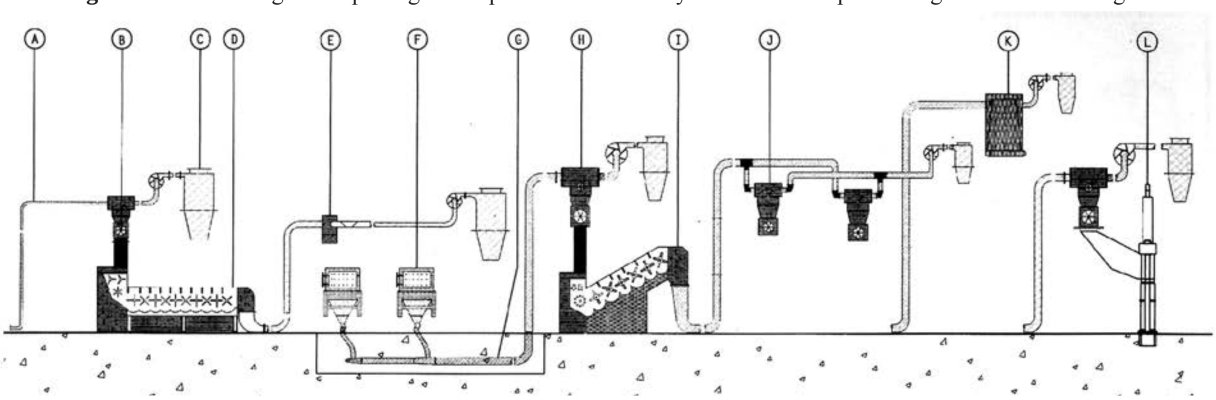


Fig. 1 Schematic diagram depicting the sequence of machinery used in cotton processing in a modernized gin



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 pala house to press house, L-Bale press chart of the machinery used for cotton processing and also the waste generated at different stages of processing. The moisture content at different stages of cotton processing was measured. Five samples were collected at each stage at regular intervals for moisture content measurement. The waste at different places such as at stone catcher, pre-cleaner, lint cleaner, different cyclones, kawadi from the auto feeder, and yellow pickings from the roller were collected. The cleaning waste from the platform, gin house, press house and pala house was also collected and weighed separately. The lint obtained was pressed to make the bales and they were weighed. The seed were collected from the platform and weighed. The visible and invisible processing loss in the modernized ginnery was then determined.

Results and Discussion

Table 1 shows the total visible waste generated during the processing from the first and second picking. Visible waste of 64 kg was obtained after processing 5,865 kg of first picked seed cotton. The ginning percentage of the first picked cotton was 35 %. The initial moisture content in the first picked seed cotton varied from 10 to 11 % with an average of 10.5 %. Moisture content decreased when the cotton passed through the different conveying systems. The moisture content during ginning and pressing was about 8 % by using appropriate moisture application systems. This was the recommended moisture content for good ginning and pressing.

Visible waste of 79.4 kg was obtained after processing 5,000 kg of second picked seed cotton. The ginning percentage of the second picked cotton was 34.7 %. The initial moisture content of the second picked seed cotton varied from 6.5 to 7.5 % with an average of 7.0 %. Humidification was used to moisturize the cotton and lint during ginning and pressing. At the bale stage, the moisture content in the lint was between 7.8 to 8.3 % with an average of 8 %.

Table 2 shows the visible processing loss in percent of the total weight of seed cotton at different stages. The visible loss at the pre-cleaning stage was 0.56 % in first and 0.70 % in second picking cotton. Similarly, at the lint cleaner, the visible loss was 0.11 % and 0.20 % for first and second picking, respectively. The total visible processing loss was 1.1 % and 1.6 % for first picking and second picking cotton, respectively. The total visible loss included the loss at the pre-cleaner and lint cleaner, fly waste from different cyclones, kawadi from auto-feeder, yellow picking from the ginning roller and the cleaning waste from the seed cotton platform, stone catcher, gin house, pala house and press house.

The total processing loss for the first picking cotton of MECH-1 variety was 1.8 %, which included visible loss (1.1 %) and invisible loss (0.7 %) by weight of raw cotton. The total processing loss for second picking cotton of LRA-5166 variety was 3.3 %, which included visible loss (1.6 %) and invisible loss (1.7 %) by weight of raw cotton. It should be possible to recover up to 0.5 % good cotton from the visible waste generated during cotton processing. In conventional gins the processing loss varied between 0.5 and 1 % depending on the type and quality of cotton ginned. (Report MSCCGMF, 2003)

The processing loss varied with cotton to be ginned, condition of the cotton, amount and nature of trash in the cotton, time of harvest, cotton moisture content at the time of processing and types and condition of machinery used. The good cotton and lint could be recovered from the visible waste. The ginning waste could be used to prepare value added products for biogas generation.

Table 1 Visible waste generated in cotton processing in a modernized gin

Particular	First picking, Weight, (kg)	Second picking, Weight, (kg)
Seed Cotton	5,865	5,000
Lint	2,055	1,734
Seed	3,515	3,100
Total visible waste	64	79.4

Table 2 Visible processing loss at different stages in cotton processing

Particular	First Picking, %	Second Picking, %
Loss in pre- cleaner	0.56	0.70
Loss in lint cleaner	0.11	0.20
Fly waste from cyclone	0.28	0.50
Kawadi from auto feeder	0.02	0.06
Yellow picking from gin roller	0.02	0.04
Other losses (Wastages from platform, stone catcher, gin house, pala house, press house)	0.09	0.10
Total visible loss	1.1	1.6

Table 3 Total processing loss in a modernized gin

Particular	First Picking, %	Second Picking, %
Weight of lint	35.0	34.7
Weight of seed	59.9	62.0
Visible loss	1.1	1.6
Invisible loss	0.7	1.7
Total processing loss	1.8	3.3

The present case study will provide a general guideline for the ginners to know about the likely processing loss at different stages during ginning and pressing in their gins. It will help in deciding the permissible limits of processing loss at different stages such as pre-cleaner and lint cleaner. The combined permissible limit of processing loss for pre-cleaner and lint cleaner could be fixed at 1 % by weight of seed cotton. It would be possible to decide the permissible limits of total processing loss. The permissible limits of processing loss for different grades of cotton would be possible with this study. The information on the processing loss in modernized gins will be very useful to cotton traders who get their cotton ginned on a job work basis and it would also help them decide the sequence of machinery to be used before ginning the cotton to limit the processing loss to a minimum.

The processing loss could be kept below the permissible limits when ginning the cotton at recommended moisture levels, by setting and adjusting the machines for the requirement of the particular cotton, by properly maintaining the machines at regular intervals, by recovering the good cotton and lint from the waste and by proper utilization of the waste for making value added products.

Conclusions

1. Visible processing loss of 0.56 %, 0.11 % and 0.28 % was found at pre-cleaner, lint cleaner and cyclones, respectively, for first picking cotton. Similarly, visible loss of 0.70 %, 0.20 % and 0.50 % was found at the pre-cleaner, lint cleaner and cyclones, respectively, for second picking cotton.
2. The total processing loss for first picking cotton was 1.8 %, which consisted of 1.1 % visible and 0.7 % invisible loss. The total processing loss for second picking cotton was 3.3 %, which consisted of 1.6 % visible and 1.7 % invisible loss.
3. The present study will provide ginners a general guideline about the likely processing loss at different stages during cotton processing in a modernized gin. It will also help minimize the processing loss by adopting the appropriate measures.

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NEWS

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Design, Development, Testing and Comparative Evaluation of the Betel Leaf Oil Extractor

by

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Abstract

India is the largest producer of betel leaves (*Piper betle L.*) in the world producing a crop worth about Rs 9000 million every year of which over 10 percent of the leaves go waste due to various reasons. In order to minimize such waste, various ways and means have been suggested including extraction of essential oil from the surplus betel leaves. This was attempted with the Clevenger Apparatus but its performance was not satisfactory due to reasons like near-water-density of the oil and its capacity to form emulsion rapidly with water, poor oil droplet formation in the receiver tube, free movement of the oil droplets from the receiver tube back to the distillation flask, poor cooling efficiency of the apparatus, slow extraction process and loss of essential oil in vapour form. Therefore, research work was undertaken to design and develop an apparatus for extraction of essential oil from betel leaves minimizing the drawbacks. The apparatus was modified in six steps until the Betel Leaf Oil Extractor was developed with satisfactory performance. As a result of the modifications, the drawbacks were minimized and rapidity in the extraction process was achieved with a consequential saving of time and energy of 43.8 percent and 29.8 percent, respectively with an increase in oil recovery of 16.2 percent compared to the Clevenger Apparatus.

Introduction

India is the largest producer of betel leaves (*Piper betle L.*) in the world producing a crop of about Rs 9,000 million every year. About 66 percent of this production is contributed by the state of West Bengal alone that includes a 30 percent share jointly from the East and West Midnapore Districts. Betel leaf is a very perishable commodity, which is susceptible to quick spoilage due to dehydration, dechlorophyllation and fungal rot causing post-harvest losses ranging from 10-70 percent (*Guha*, 2006; *Rao* and *Narasingham*, 1977). Not only this, but during the glut season a large portion of the leaves remain unsold or sold at a throw away price (*Guha*, 2000 and 2002; *Guha* and *Jain*, 1997). Moreover, production is often so excessive that the surplus leaves are fed to the cattle and also buried into the ground to avoid environmental pollution and health hazards, which is a total waste at present (*Guha*, 2007[a, b]). In view of the above, an urgent need was felt to develop an appropriate technology to minimize such waste amounting to millions of rupees. Therefore, several research workers attempted to achieve the goal by various ways and means such as drying of the leaves (*Ramalakshmi et al.*, 2002), chemical treatment, manipulation of storage temperature, adopting better packaging materials and methods (*Guha*, 2004 Rao and Narasingham, 1977), curing and bleaching of the leaves (*Dastane*, 1958 *Sengupta*, 1996) besides essential oil extraction (*Guha*, 2000). However, lack of a suitable oil extractor hindered the progress of achieving the goal. Therefore, research work was undertaken to design, develop, test and evaluate the Betel Leaf Oil Extractor at IIT, Kharagpur, India.

Acknowledgements

The author is grateful to IIT, Kharagpur, India for providing necessary facilities and to the ICAR, New Delhi for sponsoring the research work. The author is also grateful to Prof. S. Kumar of Mathematics Department, IIT, Kharagpur for his help in statistical analysis of the data.

Design Considerations

a. Low cost,
b. Simplicity in construction,
c. Easy operation and adjustment,
d. Suitable for extraction of essential oil from betel leaves and other crops, containing essential oil nearly as dense as water, and
e. Suitable for extraction of essential oil from all other crops containing essential oil, lighter or heavier than water.

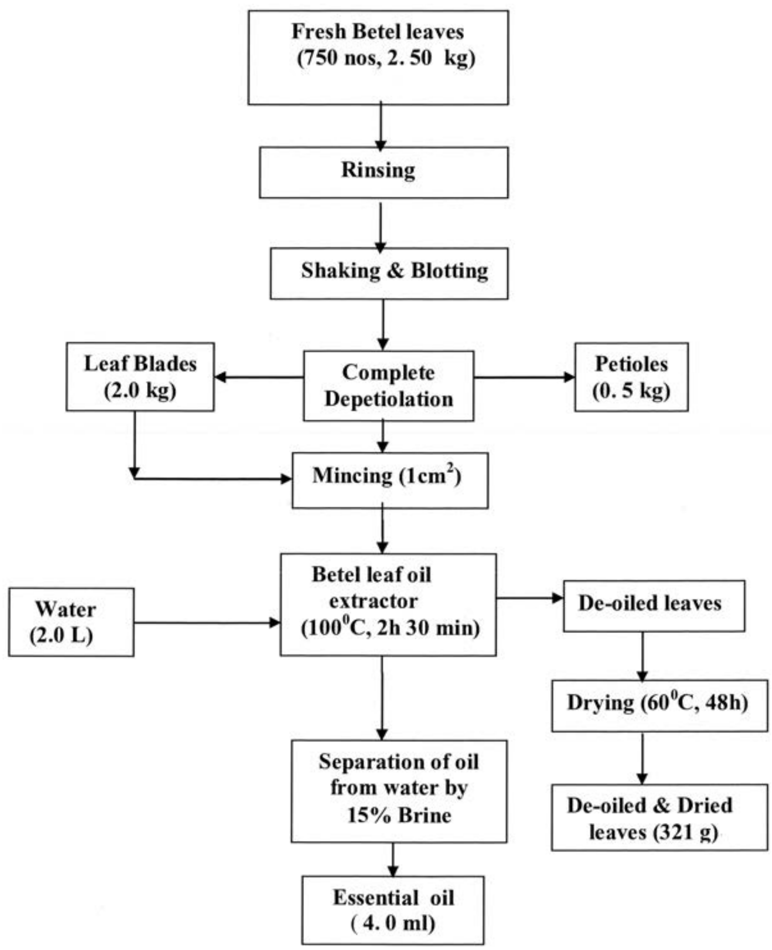
Materials and Methods

In the beginning, attempts were made to extract essential oil from betel leaves with the help of a glass made Clevenger Apparatus of 20 L size (**Fig. 2**) following the procedure shown in **Fig. 1**. A heating mantle having a maximum capacity of 3 kWh and fitted with a heating regulator was used for distillation. The extraction process was started with slow heating and gradually increased to the maximum heating capacity of the mantle. After distillation, the distillate (emulsion of oil in water) was transferred to a smaller Clevenger Apparatus (2 L size) and re-distillation was carried out using a heating mantle having maximum capacity of 0.5 kWh and fitted with a heating regulator. Cold water (~15 ^{o}C) was passed through the condenser for condensing the essential oil and water vapour during distillation. At the end of redistillation, the distillate was collected into a separating funnel of suitable size and the oil was separated from water by floating it over ~15 percent saline water that was made by adding the required amount of common salt directly into the separating funnel itself. The oil was then stored in a dark coloured bottle and sealed with an airtight lid.

The extraction process was repeated several times until all the drawbacks of the entire extraction process and that of the apparatus (**Fig. 2**) was carefully observed and recorded. In light of the above, attempts were made to minimize the drawbacks by appropriate modifications in the apparatus, which are described below:

1. The material of construction of the condenser was changed from glass (**Fig. 2**, item 4) to silver (**Fig. 3**, item 4). The silver condenser had a mass of 123 g with a length of about 42 cm covering eight hollow ball like structures of 3.5 cm diameter interconnected with hollow tube of about 1 cm length and 1.3 cm diameter each.
2. The diameter of the receiver tube was narrowed from "more than 1 cm" (**Fig. 2**, item 10) to "less than 1 cm" (**Fig. 3**, item 6), i.e. approximately 0.6 cm and a lateral tap was added for removal of oil floating over water.
3. A curved unit was added to the lower end of condenser of the Clevenger Apparatus (**Fig. 3**, item 11), which was not present in ordinary Clevenger Apparatus.
4. The vent for escaping uncondensed vapours/gases from the Clevenger Apparatus (**Fig. 2**, item 5) was added with a delivery tube ending into a beaker of cold water (~15 ^{o}C) for constructing the present apparatus (**Fig. 3**, item 13 and 14). This was named as "oil vapour trapping device".
5. The straight feed back tube in the Clevenger Apparatus (**Fig. 2**, item 7) was changed to a zigzag feed back tube in the present apparatus (**Fig. 3**, item 9).
6. The zigzag feed back tube of the

Fig. 1 Process and material flow chart for extraction of essential oil from betel leaves of Ramnagar Mitha variety with the Betel Leaf Oil Extractor



present apparatus was added with a controlling device/feed back control stopcock (**Fig. 3**, item 10), which was not present in the Clevenger Apparatus (**Fig. 2**).

The apparatus was modified in six steps as mentioned above until satisfactory performance was obtained. The inferences were drawn by testing and comparing the performance of the Betel Leaf Oil Extractor (20 L size) with the Clevenger Apparatus (20 L size) and for this, essential oil was extracted from betel leaves with both the apparatuses separately following the procedure described above and shown in **Fig. 1** with five replications. However, redistillation was not required with The Betel Leaf Oil Extractor. The volume of oil recovered during each replication of the trials was recorded along with time and electrical energy consumed for such extraction. The total time required for complete extraction with the Clevenger Apparatus was calculated by adding the time required for distillation and redistillation, whereas the total time required for Betel Leaf Oil Extractor was limited up to distillation only since redistillation was not required with the improved apparatus. Beside this, total energy requirements were also calculated following the similar procedure. The oil recovery was expressed as percentage of dry weight (v/w) whereas the extraction time and energy consumption were expressed in rounded off whole minutes/batch and kWh/batch, respectively, in both the cases. Further, from these data, increase in oil recovery and decrease in extraction time and energy consumption with the Betel Leaf Oil Extractor compared to the Clevenger Apparatus were calculated and expressed as percentage of the latter for better evaluation and comparison. These data were transformed into Angular Values for statistical analysis (R.B.D.) following the procedure descried by Fisher and Yates (1975).

Results and Discussion

Drawbacks in Extraction Process and the Apparatus

The drawbacks of the entire extraction process and that of the Clevenger Apparatus (**Fig. 2**) were carefully observed and recorded and are briefly narrated below:

1. Slow extraction process requiring more than 3 hours time,
2. Poor cooling efficiency of the glass made condenser leading to escapement of uncondensed vapour of essential oil of betel leaf,
3. Poor "oil droplet formation" due to wide receiver tube,
4. Self-stirring effect caused by the rapidly falling droplets of oil and water into the receiver tube causing quick emulsion formation in the receiver tube requiring redistillation,
5. Free movement of essential oil and emulsion from receiver tube back to the distillation flask, and
6. Near water density of essential oil of the betel leaf hindering its

Fig. 2 Schematic diagram of clevenger apparatus

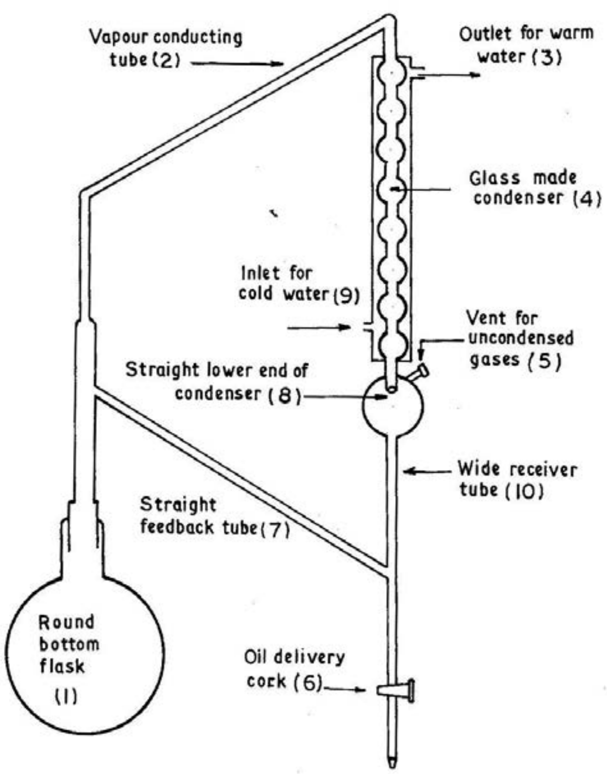
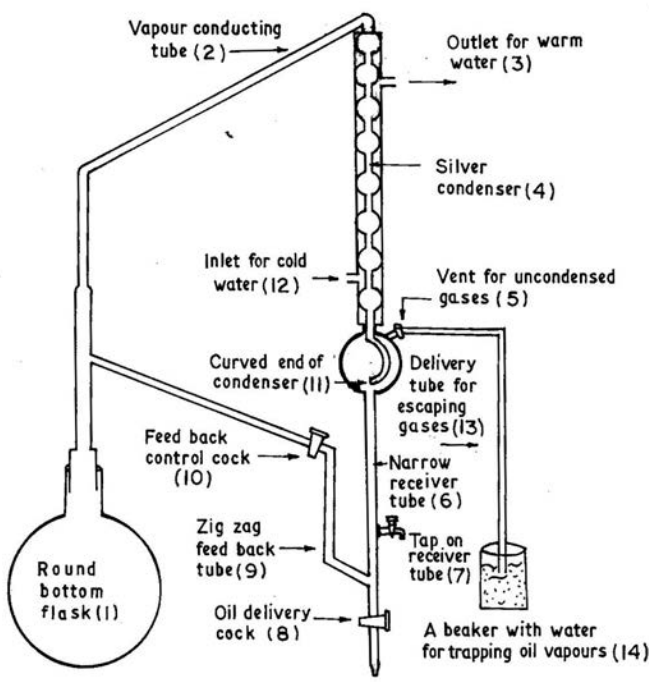


Fig.3 Schematic diagram of Betel leaf oil extractor



separation from water.

All these factors jointly reduced oil recovery and increased the loss of essential oil and energy consumption.

Modifications and Improvements in the Present Design

The observations recorded on the essential oil extraction trials conducted with the Clevenger Apparatus indicated that its performance was not satisfactory due to various drawbacks as discussed above. In light of such study, suitable modifications were made to construct the Betel Leaf Oil Extractor and to develop the following components for efficient extraction of essential oil (**Fig. 3**):

1. Distillation flask (Round bottom flask)
2. Vapour conducting tube (Vapour outlet tube)
3. Metallic condenser (Silver condenser)
4. Curved end of the condenser
5. Bulb for holding uncondensed vapour
6. Narrow Oil collection tube (Receiver tube) with lateral tap
7. Zigzag feed back tube with a flow controlling device
8. An oil vapour trapping device

The resultant effects of the above mentioned modifications are discussed below:

The glass made condenser of the Clevenger Apparatus imparted slow cooling effect and, as a result, profuse uncondensed oil vapour escaped out of the system into air, which could be detected by the particular aromatic smell (smell of smashed betel leaves) in the surrounding atmosphere. Thus, oil recovery was reduced. Therefore, the glass made condenser was replaced by a metallic condenser (silver made) in the Betel leaf Oil Extractor (**Fig. 3**, item 4). As a result of this replacement, quick cooling took place with the present apparatus and, therefore, no uncondensed oil vapour was lost and oil recovery was increased.

After condensation of vapour, the oil and water droplets rapidly fell on the surface of water kept in the receiver tube of a Clevenger Apparatus with kinetic energy acquired through the acceleration due to gravity. These rapidly falling droplets created a condition of self-stirring effect. Consequently, an emulsion (oil in water) was formed which remained suspended throughout the water column in the receiver tube. Therefore, the oil droplets did not localize at any point in the receiver tube of the Clevenger Apparatus. Rather, the droplets remained scattered throughout the water column in the receiver tube (**Fig. 2**, item 10) and consequently, separation of oil from water and its collection became difficult. Moreover, the oil droplets remained suspended in the form of an emulsion which could easily go back to the distillation flask through the feed back tube. This ultimately decreased oil recovery and increased extraction time and energy consumption. To overcome this, a curved unit was added to the lower end of the condenser. This curved unit of The Betel Leaf Oil Extractor (**Fig. 3**, item 11) intercepted the rapidly falling droplets and absorbed the kinetic energy contained in them. Therefore, the droplets could not make any impact on the surface of water kept in the receiver tube (**Fig. 3**, item 6). Consequently, emulsion was not formed and the oil droplets got localized at one point to form a distinct and clear-cut oil layer on the surface of water kept in the receiver tube. Thus, oil recovery was increased with the present apparatus.

There was no device in the Clevenger Apparatus to minimize the distance between "water surface in the receiver tube" and the "lower end of the condenser releasing the droplets." Therefore, formation of emulsion took place as discussed above. To stop this, a flow-controlling device (feedback control cock) was added to the Betel Leaf Oil Extractor (**Fig. 3**, item 10). This device embedded on the zigzag feed back tube, helped to maintain a minimum distance between "water surface in the receiver tube" and the "lower end (curved end) of the condenser". This brought about the fact that the oil and water droplets crossed the most minimum distance while falling from the lower end (curved end) of the condensation unit to the surface of water kept in the receiver tube. Such minimum distance minimized accumulation of kinetic energy in the falling droplets and thereby minimized self-stirring effect and ultimately, emulsion formation was reduced. Consequently, oil recovery was increased while extraction time and energy consumption were reduced.

The tiny oil droplets traveled easily from the receiver tube to the Distillation flask through the straight feed back tube of the Clevenger Apparatus (**Fig. 2**, item 7). This decreased oil recovery and increased extraction time and energy consumption. To overcome this, the straight feed back tube was replaced by a zigzag feedback tube in the Betel Leaf Oil Extractor (**Fig. 3**, item 9). This zigzag feed back tube obstructed free movement of oil droplets. The maximum amount of obstruction was given by the perpendicular portion of the zigzag feed back tube taking advantage of the gravitational pull and as such this tube obstructed the oil droplets from going back to the distillation flask from the receiver tube. Such obstruction in turn increased oil recovery and decreased extraction time and energy consumption.

In the wider receiver tube of the Clevenger Apparatus (**Fig. 2**, item 10) the oil layer, if formed, broke down quickly into small droplets and the oil droplets got mixed up with water in the receiver tube to form an emulsion. This decreased the oil recovery. Therefore, the diameter of the receiver tube was reduced to less than one centimeter (approximately 0.6 cm). As a result, a distinct and clear-cut oil layer was formed and retained inside the receiver tube of the Betel Leaf Oil Extractor (**Fig. 3**, item 6), which increased the oil recovery. However, the lateral tap (**Fig. 3**, item 7) constructed on the receiver tube for removal of oil did not perform well and therefore, was discarded at the final stage of construction.

The gas delivery tube connected to the "vent for escaping gasses" in The Betel Leaf Oil Extractor (**Fig. 3**, item 5) led the uncondensed vapours to a beaker containing cold water for further condensation and mixing with water and forming an emulsion. In this way, the oil vapours that might be lost through the vent of Clevenger Apparatus (**Fig. 2**, item 5), reducing oil recovery, was trapped in cold water. This cold water gradually turned into an emulsion and the oil present in it was subsequently recovered by redistillation. This increased oil recovery to a further extent. However, due to quick cooling effect imparted by the silver condenser no uncondensed oil vapour escaped out into the surroundings, unlike the Clevenger Apparatus. Therefore, at the final stage of construction this gas delivery tube and beaker (**Fig. 3**, item 13 and 14) was eliminated.

Near water density (–0.99 g/ml) of essential oil of betel leaf was the main hindrance against accumulation of oil at one point, i.e. on the top or bottom of the water column in the receiver tube during distillation. This density also hindered separation of oil from water after the extraction process was complete. All the above modifications directly or indirectly contributed towards minimization of the hindrances caused by the near water density of the oil. That apart, floating the oil over 15% saline water (made by adding the required amount of salt) in the separating funnel, reduced such hindrance to the minimum level and, thereby, increased the oil recovery.

Increase In Recovery of Essential Oil and Saving of Extraction Time and Energy

The average essential oil recoveries from the different varieties of betel leaves with the Betel Leaf Oil Extractor were: Sanchi 1.0%, Sada Bangla and Kali Bangla 1.7%, Ramnagar Mitha and Tamluk Mitha 2.0 %, which were 9.4 % to 16.2 % higher than that obtained with the Clevenger Apparatus (**Table 1**). That apart, the average time required for extraction of essential oil ranged from 263-267 minutes/batch with the Clevenger Apparatus including distillation and re-distillation time (**Table 2**), whereas it was only about 151-153 minutes/batch with the Betel Leaf Oil Extractor (**Table 3**). Thus, time required by the Betel Leaf Oil Extractor was much less than that required by the Clevenger Apparatus. This was because there was no need of re-distillation with the latter apparatus along with its rapidity in distillation. Thus, there was a saving of extraction time from 42.3-43.8 % with the latter compared to the former apparatus (**Table 3**); i.e. 1 hour and 56 minutes of heating time. This saving included about 1 hour and 21 minutes of re-distillation time with a heating mantle of 0.5 kWh capacity

Table 1 Comparative evaluation of performance of Clevenger apparatus and Betel leaf oil extractor on the basis of recovery of essential oil from different varieties of Betel leaves*

(%)

Varieties of betel leaf	TRIALS					Average
	I	II	III	IV	V	
	0.8	0.9	0.9	0.8	1.0	0.9
Sanchi	0.9	1.0	1.0	0.9	1.0	1.0
	12.5	11.1	11.1	12.5	0.0	9.4
	1.7	1.5	1.6	1.4	1.4	1.5
Sada Bangla	1.8	1.7	1.7	1.7	1.7	1.7
	5.9	13.3	6.3	21.4	21.4	13.7
	1.6	1.6	1.4	1.5	1.4	1.5
Kali Bangla	1.8	1.8	1.7	1.7	1.7	1.7
	12.5	12.5	21.4	13.3	21.4	16.2
	1.8	1.8	1.7	1.8	1.7	1.8
Ramnagar Mitha	2.0	2.0	1.9	2.0	1.9	2.0
	11.1	11.1	11.8	11.1	11.8	11.4
	1.7	1.8	1.7	1.9	1.7	1.8
Tamluk Mitha	2.0	2.0	2.0	2.0	1.9	2.0
	17.6	11.1	17.6	5.3	11.8	12.7

*The first and second figures show oil recovery with Clevenger Apparatus and Betel leaf oil extractor respectively, while the third figure shows percent increase in oil recovery with the latter over the former apparatus. Oil recovery is expressed as percentage of Dry Weight (v/w). CD (5%) =0.1% and CD (1%) =0.2% for increase in oil recovery.

and about 35 minutes of distillation time with a heating mantle of 3 kWh capacity (**Tables 2** and **3**). Consequently, there was total energy saving of 28.0-29.8 %; i.e. 0.82 to 0.89 kWh/batch, which included energy saving at both distillation and re-distillation stages (**Tables 4** and **5**). The statistical analysis of these data clearly shows that such increase in essential oil recovery and saving of time and energy consumption was very highly significant (**Tables 1**, **3** and **5**).

Conclusions and Recommendations

1. The present study showed that performance of the Betel Leaf Oil Extractor is much better than Clevenger Apparatus in terms of increase in recovery of essential oil, reduction in extraction time and consequential saving of electrical energy.
2. It is recommended that various product development works with essential oil of betel leaves may be taken up, such as medicines, non-tobacco based Gutkha (chewable mouth freshener), tooth paste, and mouth wash for commercial exploitation of the research work.
3. Studies may be taken up for reduction of electricity consumption by properly insulating the entire device and also by other means.
4. Studies may also be taken up to

Table 2 Time required for distillation and redistillation of essential oil from different varieties of Betel leaves with Clevenger apparatus *

(min)

Varieties of betel leaf	TRIALS I	II	III	IV	V	Average
Sanchi	194	186	185	183	180	186
	90	85	81	82	84	84
Sada Bangla	183	185	185	175	180	182
	78	80	82	87	85	82
Kali Bangla	187	188	185	180	181	184
	80	83	79	82	82	81
Ramnagar Mitha	184	185	187	181	180	183
	83	82	79	84	80	82
Tamluk Mitha	184	185	185	182	179	183
	84	79	80	89	90	84

*The first and second figures show the time required for distillation and redistillation respectively, over a heating Mantle with maximum capacity of 3 kWh and 0.5 kWh, respectively which is expressed as rounded off minutes/batch.

Table 3 Comparative evaluation of performance of Clevenger Apparatus and Betel leaf oil extractor on the basis of time required for extraction of essential oil from different varieties of betel leaves*

(min)

Varieties of betel leaf	TRIALS I	II	III	IV	V	Average
Sanchi	248	271	266	265	264	263
	150	155	53	150	150	152
	47.2 %	42.8 %	42.5 %	43.4 %	43.2 %	43.8 %
Sada Bangla	261	265	267	262	265	264
	156	150	155	149	150	152
	40.2 %	43.4 %	41.9 %	43.1 %	43.4 %	42.4 %
Kali Bangla	267	269	264	262	263	265
	158	152	155	150	150	153
	40.8 %	43.9 %	41.3 %	42.7 %	43.0 %	42.3 %
Ramnagar Mitha	267	267	266	265	260	265
	157	150	151	150	156	153
	41.2 %	43.8 %	43.2 %	43.4 %	40.0 %	42.3 %
Tamluk Mitha	268	264	265	271	269	267
	148	150	154	153	150	151
	44.8 %	43.2 %	41.9 %	43.5 %	44.2 %	43.5 %

*The first and second figures show the total time required for extraction with Clevenger apparatus and Betel leaf oil extractor respectively, while the third figure shows percent saving of time with the latter over the former apparatus. CD (5 %) = 4 minutes and CD (1 %) = 6 minutes for saving of time.

explore the possibilities of using the de-oiled leaves (by-product) as fuel for meeting the energy required for heating the distillation flask and manufacturing of organic manure as well.

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Table 4 Electrical energy required for distillation and redistillation of essential oil from different varieties of Betel leaves with Clevenger apparatus*

(kWh)

Varieties of betel leaf	TRIALS					Average
	I	II	III	IV	V	
Sanchi	2. 68	2. 57	2.55	2.53	2.48	2.56
	0.45	0.43	0.41	0.41	0.42	0.42
Sada Bangla	2.53	2.55	2.55	2.42	2.48	2.51
	0.39	0.40	0.41	0.44	0.43	0.41
Kali Bangla	2.58	2.59	2.55	2.48	2.50	2.54
	0.40	0.42	0.40	0.41	0.41	0.41
Ramnagar Mitha	2.54	2.55	2.58	2.50	2.48	2.53
	0.42	0.41	0.40	0.42	0.40	0.41
Tamluk Mitha	2.54	2.55	2.55	2.51	2.47	2.53
	0.42	0.40	0.40	0.45	0.45	0.42

*The first and second figures show Electrical energy required for distillation and redistillation, respectively.

Table 5 Comparative evaluation of performance of Clevenger Apparatus and Betel leaf oil extractor on the basis of Electrical energy required for extraction of essential oil from different varieties of betel leaves*

(kWh)

Varieties of betel leaf	TRIALS					Average
	I	II	III	IV	V	
Sanchi	3.13	2.99	2.96	2.94	2.90	2.98
	2.07	2.14	2.11	2.07	2.07	2.09
	33.9 %	28.4 %	28.7 %	29.6 %	28.6 %	29.8 %
Sada Bangla	2.91	2.95	2.96	2.85	2.91	2.92
	2.15	2.07	2.14	2.06	2.07	2.10
	26.1 %	29.8 %	27.7 %	27.7 %	28.9 %	28.0 %
Kali Bangla	2.98	3.01	2.95	2.89	2.91	2.95
	2.18	2.10	2.14	2.07	2.07	2.11
	26.8 %	30.2 %	27.5 %	28.4 %	28.9 %	28.4 %
Ramnagar Mitha	2.95	2.96	2.98	2.92	2.88	2.94
	2.17	2.07	2.08	2.07	2.15	2.11
	26.4 %	30.1 %	30.2 %	29.1 %	25.3 %	28.2 %
Tamluk Mitha	2.96	2.95	2.95	2.96	2.92	2.95
	2.04	2.07	2.13	2.11	2.07	2.08
	31.1 %	29.8 %	27.8 %	28.7 %	29.1 %	29.3 %

*The first and second figures show the total electrical energy required for distillation with Clevenger Apparatus and Betel leaf oil extractor respectively, while the third figure shows saving of electrical energy with the latter over the former apparatus. CD (5%) = 0.06 kWh and CD (1%) = 0.1 kWh for saving of electrical energy.

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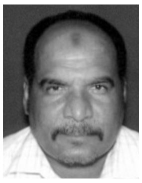
Spray Droplet Number and Volume Distribution as Affected by Pressure and Forward Speed

by



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Abstract

The influence of spray application pressure and forward speed on droplet number and volume distribution was studied. Treatments included pressures of 4 and 2 bars and forward speeds of 5.4 km/hr, 7.9 km/hr and 10.8 km/hr. All treatments were applied by one nozzle size at one rate of spray application.

When pressure was increased from 2 bars to 4 bars, the average droplet density per square centimeter was increased by 52 %. Increasing the forward speed from 5.4 km/hr to 7.9 km/hr increased the droplet density/cm^2 by 18.28 %. Further increase in speed to 10.8 km/hr increased the droplet density by 38.2 %. Statistical analysis showed highly significant difference at the 1 % level between the effects of pressure and speed on droplet density.

The lower pressure (2 bars) with the highest forward speed (10.8 km/hr) resulted in the highest percentage (39 %) of droplet size (30-100 μm) which was in favour of controlling insects. For all levels of speed, higher pressure showed the highest uniformity of distribution of spray droplets and lower volume median diameter (VMD) and number median diameter (NMD) values. The smallest ratio of VMD/NMD (1.77) with narrow droplet spectrum was recorded at higher pressure (4 bars) and a forward speed of (7.9 Km/hr).

Introduction

Improvements in agrochemical application technology emphasize uniform application, precise metering control, optimum droplet size and safety in the working environment. Therefore, selection of suitable application methods and parameters are equally important for the effectiveness of the chemical. To achieve even distribution, good coverage and proper physical and biological effects, it is important to consider droplet spectrum, droplet density, spray volume, forward speed and application pressure. Successful application means the application of the required quantity of the chemical at the right time with complete coverage to the target in an environmentally and hygienically safe way (*Gadalla*, 1989). Degree of coverage on the target with individual droplets determines the biological efficiency of the spray. The more droplets impinging per unit area, the better the biological efficiency of the spray. The improvements in spraying technologies have been achieved as a result of evolution rather than revolution. The trend followed has been toward reduced volume of spraying through high ground speed and adequate pressure. Low spray application efficiency is undesirable since it reduces the effectiveness of chemicals, increases the applications cost, results in off target spray and leads to risk of environmental pollution and killing of non-target creatures. Since pesticides are expensive and undesirable in the environment for many reasons, they must be applied precisely on the target at the correct amount (*Ricarlo*, 2001).

There are several methods for evaluation and measurement of spray volume and droplet distribution patterns, droplet density, droplet volume median diameter (VMD) and number median diameter (NMD) (*Power et al.*, 2006; *Jain et al.*, 2006; and *Adnan* and *Khdair*, 2003). Matthews (1992) concluded that a few large spray droplets can account for a large proportion of spray and so can increase the volume of VMD, which does not indicate the range of droplet sizes. Omer and Zakaria (1993) and Kathirve et al. (2007) also concluded that spray droplet spectrum containing small droplets (VMD = 19 μm) caused significant effect on insects compared to a coarse spray (VMD

= 210 µm). Miller (1988) mentioned that hydraulic nozzles produced droplets less than 80 µm in size and VMD of 278 µm and would be used at relatively high volume to give good coverage and efficient control. Therefore, it is important to control the spray performance and distribution (Bob 1991; Legg and Miller, 1989; and Hobson et al., 1993), through selection and the use of proper sprayer and components and applying the spray effectively and efficiently with correct dose at the right time.

The main objective of the present study was to investigate the effect of forward speed and application pressure on spray droplet size and volume distribution.

Materials and Methods

An experiment was carried out to study the effect of forward speed and discharge pressure on selected spray properties during two seasons in the field. In both seasons, the experiment was conducted during Nov.-Feb. The climatic temperature, relative humidity and wind speed data at the time of spray application are given in **Fig. 1**. The experimental treatments were a combination of three forward speeds (S_1 = 5.4 km/h, S_2 = 7.9 km/h, S_3 = 10.8 km/h) and two pump pressures (P_1 = 4 bar, P_2 = 2 bar). These treatments were replicated four times and distributed randomly in plots (50 × 8 m) that were arranged in a randomized complete block design (RCBD). A two-wheel drive tractor (72 hp) and a mounted ground sprayer (600 ml)

Fig. 1 Readings of (a) Temperature (b) Relative Humidity (c) Wind speed during experimental period

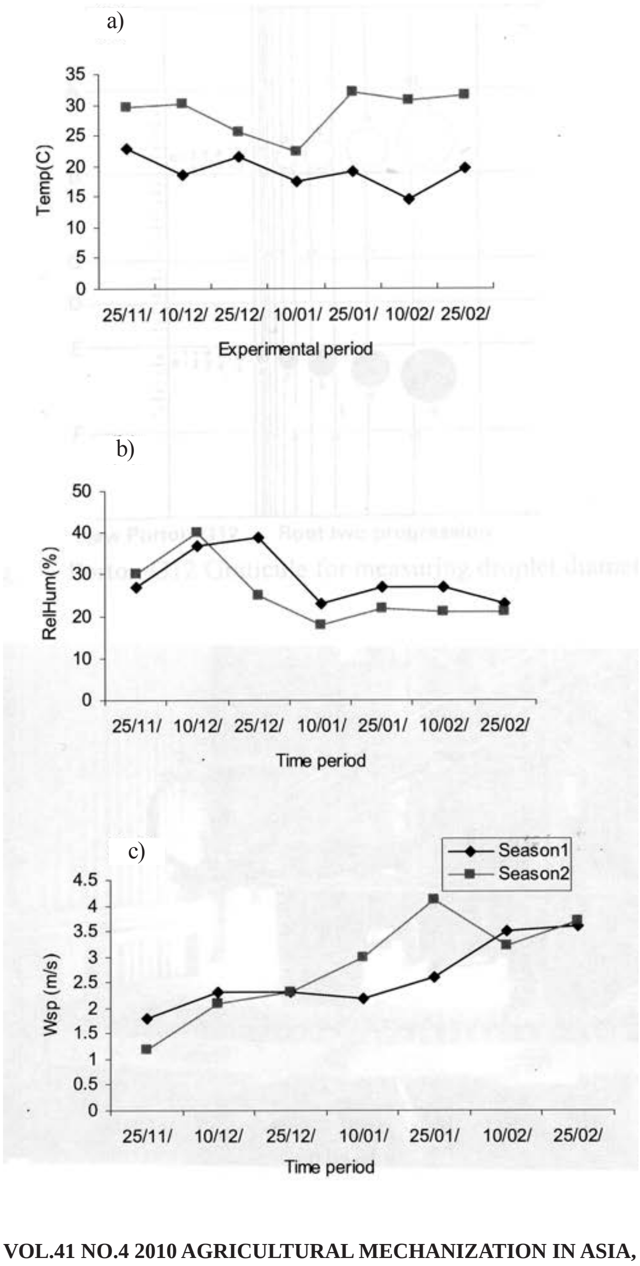


FIg. 2 Porton G12 Graticule for measuring droplet diameter

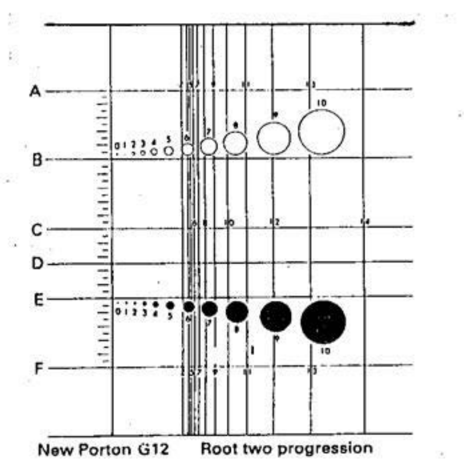
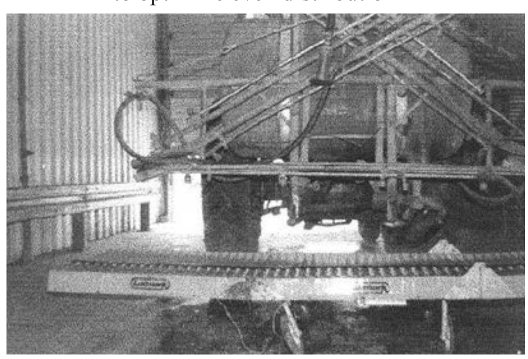


Fig. 3 The Patternator used for calibration of insecticide sprayer to optimize even distribution



were used for chemical spraying in the field.

Other equipment and materials included, a patternator (**Fig. 2**), pocket microscope, water sensitive paper, magnesium oxide coated slides, a proton G12 graticule (**Fig. 3**), stop watch, a measuring tape and buckets and graduated cylinders. Before treatment application, the sprayer was calibrated for spray volume rate (lit/ha) at the different treatments as follows:

Spray volume rate (lit/ha) = 10000 × total flow rate (lit/min) / W (m) × Speed (m/min)

Where; W = operation width in meters

Table 1 shows the spray volume rate and the nozzle flow rate for the different treatments. Droplet number per unit area for the dynamic droplet distribution was measured by fixing four water sensitive papers on selected areas in each plot to receive spray droplets at the centre of the plot. After spray application papers were collected. Droplet distribution by number across spray lines and coefficients of variability were calculated. The data were plotted to a give clear picture of uniformity of droplets distribution by number.

Droplet size under static conditions was measured by using magnesium oxide coated slides. The coated slides prepared in the field and were moved quickly under the spray nozzles for droplet collection and measurements. Spray volume distribution was measured using a patternator. It was positioned under the sprayer boom. The liquid of the sprayer was sprayed from the nozzles into sloped channels of the patternator and then drained into tubes until at least one of the tubes was filled to the maximum level. The variation in spray distribution along the boom length was investigated and coefficient of variation was calculated. The obtained flow rate from each tube was plotted to give clear picture of uniformity of volume distribution across the spray line.

Results and Discussion

Droplet Density (Droplet No./Square Centimeter)

Increasing the pressure and forward speed generally increased the droplet density in both seasons (**Table 2**). As the speed was increased from S_1 (5.4 Km/h) to S_3 (10.8 Km/h), the average droplet density was increased from 60.1 to 86.1 droplets per square meter. When the pressure of spray application was increased from 2 bars to 4 bars, the droplet density was increased by 58.9 % in the first season and by 44.9 % in the second season. Statistical analysis showed highly significant difference at the 1 % level between the effects of pressure and speed on droplet density while the interaction effect was significant at 5 % level. Duncan multiple range tests showed significant differences between the effects of low and high pressure and between the effects of three levels of forward speed on droplet density in both seasons (**Table 2**). Increasing the forward speed and application increased the flow rate per nozzle and broke the spray into small droplets and, therefore, increased the droplet number per cm^2. This was in line with the findings of BOB (1991) and Ahmed (1994).

Droplet Size Distribution by Number and Volume

Fig. 4(a-f) shows droplet size distribution by number for the different treatments. Higher pressure with different speeds recorded the highest percentage of mean size diameter (25-70 µm) while the low pressure with the three range of speeds recorded the highest percentage of mean size diameter (70-198 µm). **Fig. 5**(g-l) shows droplet size distribution by volume. The higher pressure with the three levels of speed gave the highest percentage mean size diameter of 278.5 µm, where as the lower pressure with the three speeds produced the highest percentage of mean size diameter of 392 µm. Matthews (1992) and Jaycee (1975) revealed that the optimum droplet size range which may give the best control is 30-100 µm. The lighter pressure with highest speed (P_1S_3) resulted in the highest percentage of droplet size, which was in favour of controlling insects (**Table 3**). Very fine droplets ≤ 30 µm drifted away from the target while larger droplets ≥ 100 µm had high kinetic energy and bounced off the target or gathered to run to

Table 1 Nozzle angle, flow rates and spray volume application rate

Treatments	Nozzle angle	Nozzle flow rate l/min	Spray volume lit/ha
S1 P1	71	2.00	444.4
S1 P2	67	1.41	313.3
S2 P1	70	1.96	594.5
S2 P2	66	1.38	207.4
S3 P1	71	1.82	202.1
S3 P2	65	1.48	164.4

Table 2 Effect of tractor forward speed and spray application presure on droplet density

Treatments	Pressure		
Speed	P1	P2	mean
S1	75.4[c]	44.8[e]	60.3[c]
S2	85.2[b]	61.2[d]	73.3[b]
S3	103.2[a]	68.8[c]	85.1[a]
mean	88.1[a]	58.3[h]	

SE (S) = 1.35, SE (P) = 1.1, SE (S × P) = 1.91, C.V. = 5.36

Fig. 4 (a-f) Droplet size distribution by number as affected by type of treatments

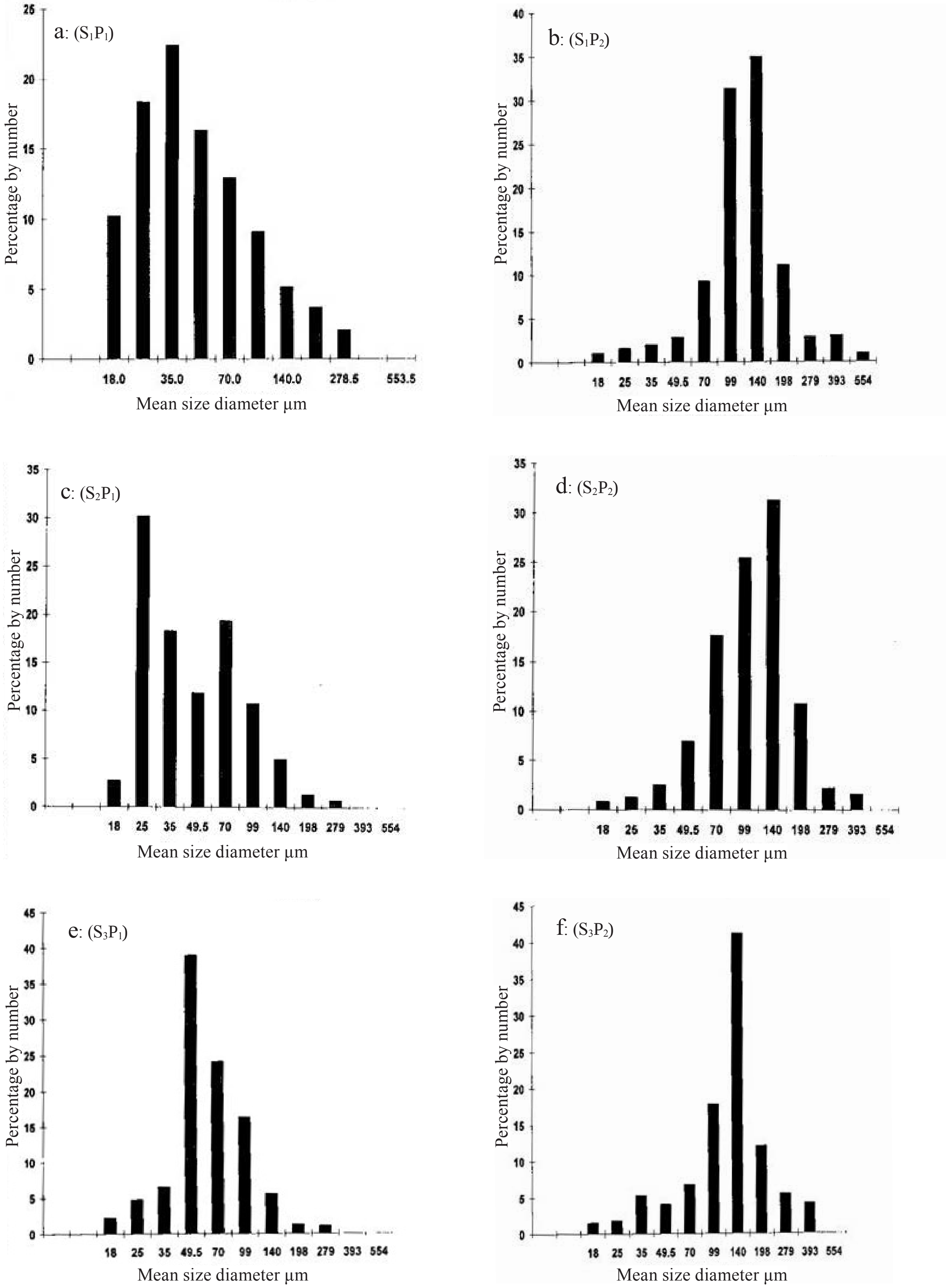
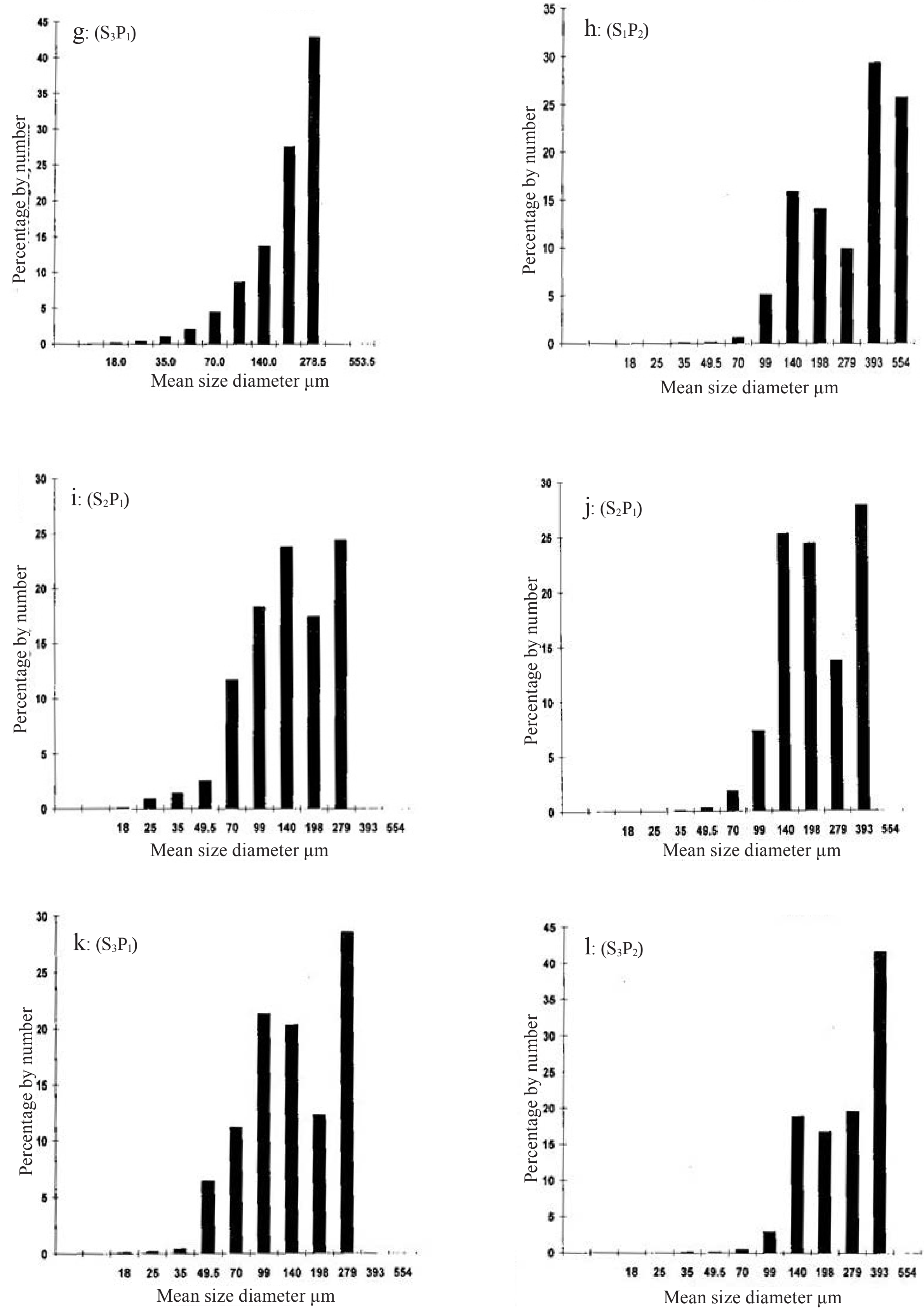


Fig. 5 (g-l) Droplet size distribution by volume as affected by type of treatments



the ground. It was clear that the high pressure increased the break of droplets into desired size and effective in control. This agreed with the findings of Matthews (1992, Matthews (1979) and Bau (1980). The droplet size distribution was often presented by volume median diameter (VMD) and number median diameter (NMD). The ratio of VMD/NMD presented the width of droplet spectrum. The smaller this ratio means the droplets are narrow in spectrum and more uniform in size (*Kathirve et al*., 2007). It was clear that the lower pressure with the lowest speed (P_2S_1) resulted in the highest VMD value (270 µm), whereas the higher pressure with the highest speed (P_1S_3) gave the lowest VMD value (120 µm) (**Table 5**). The lowest value of NMD (35 µm) was recorded with the treatments P_1S_1 and P_1S_2, while the highest value (110 µm) was given by the lower pressure with the highest speed (P_2S_3). The smallest ratio of VMD/NMD (1.77) was given by the treatment P_2S_2, whereas the highest ratio (5.14) was recorded by the higher pressure with the lowest speed (P_1S_1). In general, the results revealed that higher pressure produced low VMD and low NMD, whereas changing of speed did not affect VMD and NMD (**Table 5**). The values of VMD were usually larger than NMD. This might have been due to a few large droplets in the spectrum. This agreeded with Matthews (1975), Gadalla (1989) and Ahmed (1994).

Spray Uniformity Distribution and Static Volume and Dynamic Droplet Number

The result of dynamic number distribution showed that the higher pressure with the highest speed gave the highest mean droplet number (108.3) and lowest coefficient of variation (22.8 %) and, therefore, the highest uniformity of distribution. Where as, the lower pressure with the lowest speed produced the lowest mean droplet number (37.31), the highest coefficient of variability (29.1 %) and the lowest uniformity of distribution. The results of the static volume distribution showed that the higher pressure with the lowest speed gave the highest mean volume distribution (72.6 ml), the lowest coefficient of variation (9.3 %) and the highest uniformity of distribution (**Table 5**). The lower pressure with the highest speed recorded the lowest mean volume distribution (60.7 ml), the highest coefficient of variation (14.2 %) and the lowest uniformity of distribution.

The high pressure gave the highest uniformity of distribution for both static volume distribution and dynamic droplet number distribution. The coefficient of variation was higher for the dynamic condition compared to the static one. That could have been due to the motion of the tractor in the field and climatic condition effects. This agreed with Fozkan *et al.* (1992), Azimi *et al.* (1985) and Ahmed (1994).

Conclusions

The following conclusions may be drawn from the present study:

1. Increasing spray application pressure and forward speed increased droplet density/cm^2.
2. The lower pressure with the highest forward speed resulted in the highest percentage of droplet size (30-100 µm), which was in favour of proper control of insects.
3. The higher pressure produced low VMD and NMD with better uniformity of spray droplet distribution and narrow spectrum.

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Table 3 Volume percentages in droplets size range for different treatments

Treatments	Applic. Press	Volume (%) in droplet size		
		30-100 µm	> 30 µm	< 100 µm
P_1S_1	4	15.74	0.34	83.93
P_2S_1	2	5.57	0.01	94.42
P_1S_2	4	33.71	0.85	65.44
P_2S_2	2	9.27	0.01	90.72
P_1S_3	4	39.04	0.11	60.84
P_2S_3	2	3.38	0.01	96.61

Table 4 Effect of application pressure and forward speed on volume of distribution of the spray

Treatment	Flow rate L/min	Volume Distribution ml		Droplet distribution No	
		X	CV %	X	CV %
P_1S_1	2.0	72.64	9.30	61.27	24.92
P_2S_1	1.96	72.06	1.66	78.93	23.60
P_1S_2	1.82	72.04	12.22	108.34	22.77
P_2S_2	1.41	64.72	10.19	37.34	29.13
P_1S_3	1.38	66.88	13.53	48.34	25.57
P_2S_3	1.48	60.7	14.2	54.25	25.63

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Table 5 Volume median diameter, number median diameter and VMD/NMD ratios as affected by treatment type

Treatment	Application press (bar)	VMD	NMD	VMD / NMD
P_1S_1	4	180	35	5.14
P_2S_1	2	270	90	3.0
P_1S_2	4	140	35	4.0
P_2S_2	2	170	96	1.77
P_1S_3	4	120	48	2.5
P_2S_3	2	240	115	2.18

Effect of Soil Compaction on Growth of Corn (*Zea Mays L*) and Mungbean (*Vigna Radiata (L) Wilczek*)

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Abstract

The effect of soil compaction on soil-bulk density, soil penetration resistance, and corn and mungbean germination, growth and yield was investigated in a sandy loam soil at the agriculture farm of the PNG University of Technology, Lae, Papua New Guinea. The treatments used were: no compaction (T0), 20 × soil compaction (T1) and 50 × soil compaction (T2) by using a 30 kw tractor. The results obtained showed that high bulk density was observed at 15 cm depth in the two compaction induced treatments whereas at 30 cm depth, bulk density tended to decrease. Penetration resistance (PR) increased in soil strength as depth increased in the two compaction treatments. Low germination, poor growth performance and low yield were observed in the T1 and T2 treatments. This study indicated that soil compaction in sandy loam soil was one of the factors that affected the soil physical properties and the growth and yield performance of corn and mungbean.

Introduction

Human induced agricultural land degradation is wide spread in irrigated and rain fed land in both tropical and temperate zones. Land degradation represents a challenge to the sustainability of farming systems in all regions, even those of low population densities. Edmundo, J. Hertz (2001) stated that modern agriculture would be unthinkable without the utilization of tractors and machines. Farmers used them, essentially, to increase their work capacity and the productivity of the land and labour. Soil degradation, through human activities and natural forces has reduced the productivity of soils and damaged adjacent ecosystems. Soil degradation can result from soil compaction, accelerated soil erosion, loss of vegetative cover, oxidation of soil organic matter, and impairment of other soil physical, chemical and biological properties. It is believed that compaction affects the physical, chemical and biological properties of soils, and has been considered as one of the main causes of agricultural soil degradation worldwide (Soane, 1982).

Cropping systems across different landscapes and soil types are suffering from soil compaction. Compaction is a continuous process ultimately resulting in a loss of soil macro-porosity, that leads to low storage supply of water and oxygen, and increased soil strength. The effect of compaction on plant growth and yield depends on the rate of root growth, soil type, and weather conditions. As field machines become heavier and the motivation for the grower to become more efficient with his time, soil compaction becomes a much greater concern. Compaction drastically reduces water infiltration rates due to the smaller pores causing fewer well-defined natural drainage channels in the soils (Voorhees, 1985). Unfortunately, this cycle sets up a long list of chain-event problems. Greater surface wetness with increased water run off, results in increased surface soil erosion. It requires longer drying times, which in turn delays planting and harvesting. As a result, it ultimately leads to decreased crop yields. In addition, roots are not able to fully develop in compact soils, resulting in reduced access to soil moisture and nutrients.

The major impact of soil compaction is the alteration of soil physical properties. The most notable changes are in soil bulk density, soil strength, porosity, and hydraulic properties such as infiltration rate and hydraulic conductivity. These changes affect the water and air movement through the soil. The right proportions of air and water are critical in providing a healthy root system in the soil environment (Hanna & Al-Kaisa, 2002).

When soil is compacted due to implement traffic such as tillage or fertilizer application, the major change will be in soil bulk density, in which the amount of void space is reduced and ultimately soil bulk density itself is increased (Sjoerd, 2004). If this change occurs, the total porosity is reduced due to the compaction of soil particles, which leads to reduction in the space that the water and air can occupy. The reduction in pore space not only occurs in total but also in size, restricting water and air movement. As larger pores are often filled with air rather than water, a reduction in pore sizes may lessen the ability of roots to obtain oxygen from the air above. The impact of compaction on soil physical properties, and mainly water movement, is evident through the reduction of soil hydraulic properties such as infiltration (Hanna & Al Kaisa, 2002). The reduction of this infiltration rate has a serious consequence to water quality and sediment transport, particularly on slopy soils. Compaction can contribute to earlier and larger volumes of surface runoff and major soil loss due to water erosion.

Soil compaction can have both desirable and undesirable effects on plant growth. Slightly compacted soil can speed up the rate of seed germination because it promotes good contact between the seed and soil. Whereas, moderate compaction may reduce water loss from the soil due to evaporation and, therefore, prevent the soil from drying out during growth. According to Voorhees (1985) and Hughes *et al.*, (2001) a medium textured soil, having a bulk density of 1.2 g/cm^3, is generally favourable for root growth. However, roots growing through a medium–textured soil with a bulk density near 1.2 g/cm^3 will probably not have a high degree of branching or secondary root formation. Excessive soil compaction impedes root growth and, therefore, limits the amount of soil explored by roots. This, in turn, can decrease the plants ability to take up nutrients and water. From the standpoint of crop production, the adverse effect of soil compaction on water flow and storage may be more serious than the direct effect of soil compaction on root crop.

In dry years, soil compaction can lead to stunted plants due to decreased root growth. Without timely rains and well placed fertilizers, yield reductions will occur. Soil compaction in wet years decreases soil aeration, resulting in increased denitrification (nitrogen and potassium deficiency). Reduced soil aeration affects root metabolism as well. There can also be increased risk of crop disease. All of these factors result in added stress to the crop and eventually yield loss (*Hughes et al.*, 2001). For producers, the main concern about soil compaction is its impact on yield and soil productivity. Reduction in yield also means reduction in dry matter production and eventually, the amount of crop residue left on the soil surface after harvest. The poor plant growth caused by compaction is due to the negative impact on soil moisture and air availability to the root system (Hanna and Al-Kaisa, 2002).

Enough studies have been undertaken to indicate that soil compaction does reduce the crop yield. Generally, the smaller the soil particles (i.e., clay) the more compaction, which reduces yields. Potential reductions due to compaction can be as much as 50 % of the relative yield. In this study, a high density was recorded at a depth of 15 cm but decreased at a depth of 30 cm.

Materials and Method

This study was conducted at the agricultural farm, PNG University of Technology, Lae, Morobe Province in Papua New Guinea. The farm is located at 6º S 147º E and is at an altitude of 68.9 m above sea level. The farm has an average annual precipitation in the range of 3,500-4,000 mm with average maximum and minimum temperature of 30 ºC and 27 ºC, respectively.

The following parameters were measured to assess the soil compaction; soil resistance, soil bulk density, total germination, plant growth, height and total yield. A randomized block design (RBD) with four replications in each treatment was employed. Each experimental unit (replication) consisted of an area of 10.2 m^2 (0.68 m × 15 m). The total area of the experimental plot was 122.4 m^2 (15 m × 8.16 m). The soil was compacted at two levels using various numbers of tractor passes: T0 = no compaction (control), T1 = 20 passes and T2 = 50 passes. The tractor was a 30 kw tractor with a harrow attached at the rear. The tractor ran over the entire ground area in each treatment to ensure each part was compacted by its tyres. After that, corn and mung bean seeds were sown. Weeds were removed by hand (roguing) after 20 days and 20 corn and 30 mungbean plants were maintained per replicates.

Soil compaction was applied by means of a tractor with four tyres of equal width and inflation pressure (**Fig. 1**). The tractor traveled the designated number of times across the entire soil surface in two treatments. Penetration resistance and bulk density were measured after compacting. Bulk density was measured in the two treatments with four replicates (**Fig. 2**). Bulk density was also measured in the non-compacted treatment, which served as the control. Sampling cylinders of 5 cm diameter and 5 cm height with sharp cutting edges were used in order to collect the soil samples according to the method of Blake and Hartge (1986), **Fig. 2**.

Four replicate samples were collected at three different depths in each treatment. The core samples were then weighed to obtain the fresh weight and then oven dried for 24 hours at 105 ºC in the laboratory oven. After obtaining the oven dry weight, bulk density was calculated.

Penetration resistance was measured in each treatment at the same time as the bulk density before sowing of seeds. In addition, soil moisture data were determined at the 0-5 cm, 5-15 cm and 15-30 cm depths at the same time. This was because soil moisture has strong influence on penetration resistance. Soil strength measurements were taken in each of the four replicates. The penetration resistance was measured at an increment of 5 cm up to a depth of 35 cm using a hand held penetrometer.

Germination count was done in all treatments after 5 days when all seeds had germinated. Thereafter, germination percentage was determined in all treatments to determine whether the different levels of compaction had any effect on germination. The plant height was measured after 9 days from germination and continued on a weekly basis in order to monitor the growth in the three different treatments. The GENSTAT procedure was used to conduct analysis of variance (ANOVA) to test for significant differences in corn and mungbean height and yield due to different soil compaction treatments.

Results and Discussions

Bulk density: The compaction of soil influenced the properties of both the topsoil and the subsoil. The effect of compaction was observed considering various soil parameters and crop response in a sandy loam soil. According to Tsimba *et al*., (1999), bulk density normally tends to increase with soil depth, mostly as a result of low organic matter, less aggregation and root penetration as well as pressure exerted by overlying layers. This was confirmed in the observation of untilled soil. After soil was tilled and compacted by the tractor, the soil bulk density changed because different levels of compaction applied.

Typically, most agricultural soils fall between 0.9-1.8 g/cm^3 bulk density, and beyond this range, there is root restriction in the soil. According to the result as shown in the **Table 1**, and **Fig. 3**, the bulk density of T0 treatment was between 1.49-1.53 g/cm^3.

However, after tillage operation and soil compaction, the bulk density changed in all treatments. At 5 cm depth in T1, the bulk density was 1.52g/cm^3 and in T2, the bulk density was 1.48 g/cm^3. The bulk density at 15 cm depth increased to 1.59 g/cm^3 in T1 and 1.56 g/ cm^3 in T2. However, at 30 cm depth, the bulk density in T1 and T2, decreased to 1.53 g/cm^3 and 1.43 g, respectively. The decrease in bulk density was due to sandy soil encountered at 30 cm depth.

As a result of high bulk density at 15 cm depth, pore space and soil aeration was reduced, suppressing the root spread and growth of corn and mungbean. Cornish *et al.* (1984)

Fig. 1 Compacting soil by tractor

Fig. 2 Collecting soil for bulk density test

Fig. 3 Bulk density in each compaction treatment

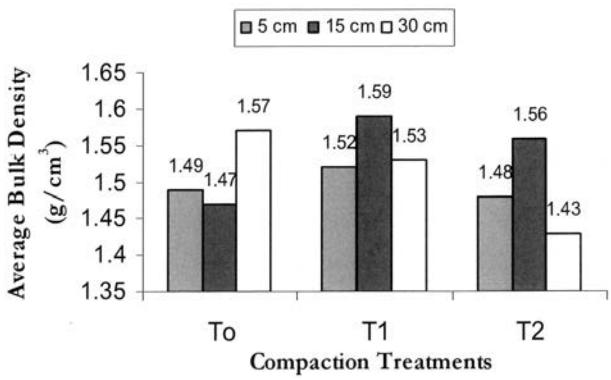


Table 1 Average bulk density at various depths in each treatment

Depth, cm	Treatments		
	T0-Control	T1-20 × compaction	T2-50 × compaction
5	1.49	1.52	1.48
15	1.50	1.59	1.56
30	1.53	1.50	1.43

confirmed in pot experiments in rye grass (Loliam perenne L.) that increasing bulk density of a sandy loam soil from 1.0 to 1.54 Mg/m^3 slightly increased root diameter and reduced root hair length. Hence, high bulk density at 15 cm depth of soil in T1 and T2 resulted in poor root spread, which limited water and nutrient absorption for corn and mungbean growth.

Penetration resistance: Penetrometric measurement showed that 20 and 50 times compaction run by the tractor increased the average penetration resistance of subsoil at 10-35 cm depth. The soil resistance increased in T1 as the depths increased. The same was also observed in T2. As illustrated in **Fig. 4**, the penetrometer resistance increased as the depth increased. In T1, the soil resistance started increasing at 5 cm depth with 44.38 N/cm^2 to 158 N/cm^2 at 35 cm depth. Similarly in T2, the soil resistance at 5 cm depth increased from 27.87 N/cm^2 to 170.29 N/cm^2 at 35 cm depth. As a result of increased soil resistance in these two compaction treatments, the pore spaces in the soil particles were reduced. This also resulted in standing water to form pools in the wheel tracks, which affected corn and mungbean germination (**Fig. 5**). The seeds that managed to germinate did not grow well in the two treatments (T1 & T2) compared to the control treatments (T0). Therefore, soil resistance due to compaction affected soil particles in reducing pore space, resisting root spread and their development.

This was proven by Masle and Passioura (1987) working with wheat (*Triticum aestivum L.*) who showed that leaf area, shoot dry weight, and root dry weight was negatively correlated with soil strength as measured by penetrometer resistance. Therefore, increased soil compaction retarded shoot growth resulting in stunted growth in corn and mungbean.

Germination: In T0 there was 100 % germination in corn and 95 % germination in mungbean, whereas, in the other two treatments (T1 and T2), the germination of corn and mungbean were poor. In T1, germination was 71 % in corn and 44 % in mungbean (**Fig. 5**). In T2, there was 64 % germination in corn and only 33 % germination in mungbean. Mungbean seeds did not germinate well, because after sowing, wet weather was experienced during the month of August and September 2007, which caused standing water to collect in the compacted zones. As a result, 56 % mungbean seeds in T1 and 67 % mungbean seeds in T2 did not germinate. Some seeds that germinated died out due to water logging in the top soil.

Therefore, according to this study, soil compaction caused reduction in soil pore space, restricting water to percolation. As a result, the standing water on the soil surface prevented seed germination.

Plant height and development: Plant height, according to the results shown in **Fig. 6**, illustrated slow or stunted growth in corn and mungbean in T1 and T2, while vigorous growth was observed in T0.

The average height of corn was 16.2 cm and 16.5 cm in T1 and T2, respectively, when compared to the corn in T0, which was 32.5 cm, 30 days after sowing.

The average height of mungbean in T1 and T2 was 9.1 cm and 5.8 cm, respectively, when compared with the mungbean growth in T0, which was 18.8 cm. After 30 days from germination, mungbean started flowering and developing beans at the average height of 18.8 cm. **Fig. 6** indicates that, mechanical soil compaction caused increased soil resistance in the soil structure. As a result, plant growth was affected causing slow and stunted growth in both treatments. According to Soane *et al.* (1982), compaction from wheel traffic in general has an adverse influence on all stages of crop growth. It was also supported by Gaultney *et al.* (1985) that the cumulative effects of subsoil compaction in Indiana, USA, severely reduced corn growth, vigor and yield.

Statistical analysis of plant height in corn and mungbean: ANOVA was specifically done to determine

Fig. 4 Penetration resistance in three treatments at different depths

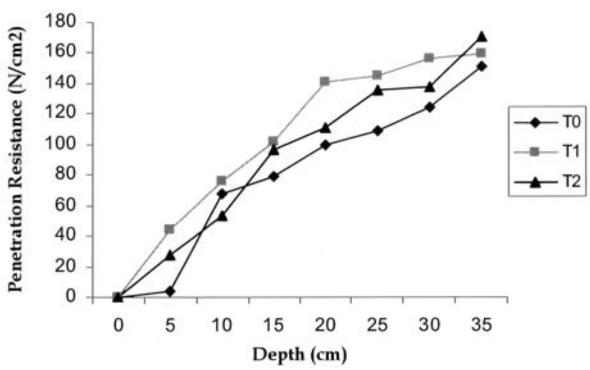
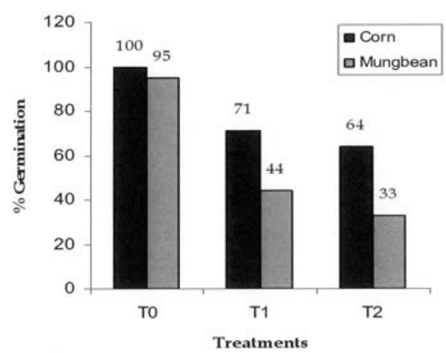


Fig. 5 Germination percentage (%) of corn and mungbean in each treatment



the significance difference in height of corn and mungbean. The F ratio of 23.94 at the 5 % and 1 % level in corn indicated highly significant difference due to different compaction treatments, and the F ratio of 6.601 at 5 % in mungbean indicated significant difference but at 1 % there was no significant difference. Therefore, the growth performance of corn and mungbean was greatly affected by the different levels of soil compaction treatments in sandy loam soil.

Yield: The total yield of corn and mungbean decreased in T1 and T2 compared to T0. As observed in **Table 2** and **Fig. 7,** the average yield of corn in T1 and T2 was 0.61 kg and 0.78 kg, respectively. This confirmed that the soil compaction in sandy soil greatly affected yield in corn production when compared against T0, which has a highest yield of 6.35 kg. The average yield of mungbean in T1 and T2 was 0.57 and 0.3 kg, respectively, as indicated in **Table 3** when compared to the yield in T0 which was 3.9 kg.

It was further confirmed that soil compaction by farm machinery does affect yield in mungbean and corn production. Therefore, according to the yield loss performance of corn and mungbean under two different compaction treatments, it was inferred that soil compaction in sandy loam soil could affect corn and mungbean yields.

Statistical analysis of yield in corn and mungbean: One-Way ANOVA was specifically done using the GENSTAT software program to determine if there was any significance difference in corn and mungbean yield due to different compaction treatments. The 0.001 F probability level indicated that the treatment means were highly significant due to different soil compaction treatment. Therefore, the results indicated that soil compaction affected corn and mungbean yield resulting in yield loss in both crops.

Conclusion

Compaction of soil by farm machinery (tractor) had a negative effect on soil properties when compared to non-compacted areas. The penetration resistance of subsoil increased depending on the degree of compaction for treatments (T1 and T2). Excessive compaction increased the bulk density of the soil at 15 cm depth in each compaction treatment. Different levels of compaction resulted in increased soil strength, causing low porosity and poor soil aeration, which inhibited the growth height of corn and mungbean in the sandy loam soil. According to these results, it was finally concluded that compaction in sandy loam soil by a heavy tractor affected corn and mungbean productivity. It restricted water movement, reduced air movement, reduced root penetration and

Fig. 6 Height of corn and mungbean in each treatment

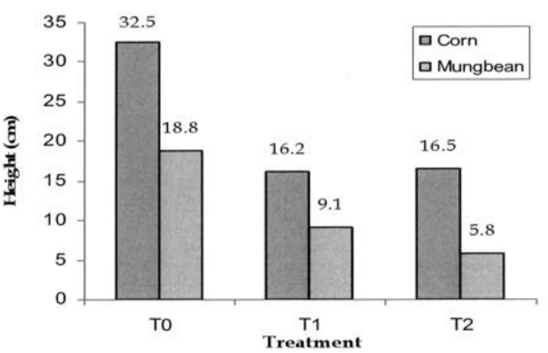


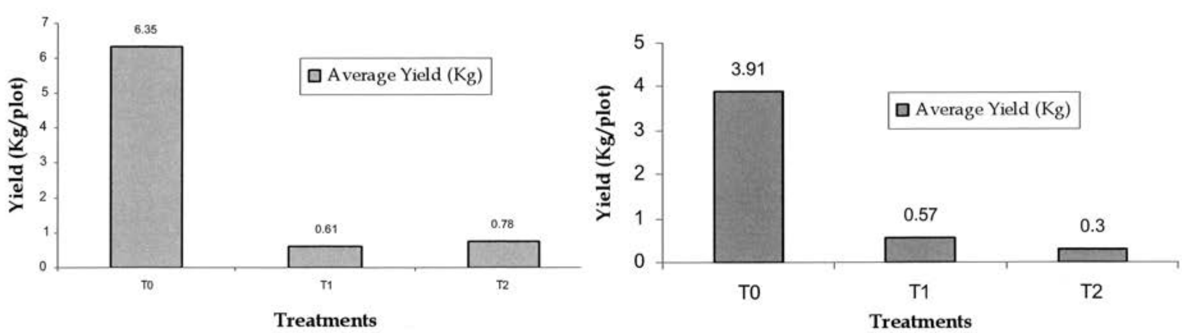
Table 2 Yield in Corn

Treatments	Total Yield (Kg/plot)	Average Yield (Kg/plot)
T0	25.4	6.35
T1	2.42	0.61
T2	3.1	0.78

Table 3 Yield in Mungbean

Treatments	Total Yield (Kg/plot)	Average Yield (Kg/plot)
T0	15.62	3.91
T1	2.26	0.57
T2	1.2	0.3

Fig.7 Average yield of Corn and Mungbean in each Treatment



reduced plant growth, ultimately resulting in yield loss.

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ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

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Assessment of Conjunctive Use Planning of Water Resources: A Case Study of Sultanpur District-Uttar Pradesh, India: **Raj Mani**, Ph. D. Scholar, Uttar Pradesh Technical University Lucknow, INDIA.; **A.N. Singh**, Ex. Director, Remote Sensing Application Centre, Uttar Pradesh, INDIA.

The amount of available water resources have been recognized as limiting factors in development of most of the semi arid regions. Optimal utilization of available surface and groundwater resources, in canal command areas would result in their better utilization by maximizing the net benefits from the crop production. But shortage of surface water supplies has increased the pressure of ground water utilization and development as well. The potential of groundwater can be used to develop conjunctive use water management plans for supplementing canal water supplies and to increase agricultural productivity. The feasibility of conjunctive use management is analyzed using a mathematical model in the Sharda sahayak command area of Sultanpur district of Uttar Pradesh-India. The water demand and available water resources in the study area in the study area in the study area are evaluated considering surface water and groundwater. This paper presents a simple economic-engineering optimization model to explore the possibilities of conjunctive use of surface and groundwater using linear programming, and to arrive at an optimal cropping pattern for optimal utilization of water for maximizing net benefits. The LINDO 6.1, optimization package has been used to arrive at optimal allocation plan of surface water and groundwater. The results indicate that conjunctive use options are feasible and can be easily implemented in the study area.

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Development and Field Evaluation of Tractor-mounted Air-assisted Sprayer for Cotton

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Abstract

A tractor mounted air-assisted sprayer was developed and evaluated in a field of cotton. The air-assisted system of the sprayer consisted of an axial flow fan, fan casing and sleeves with 40 mm diameter holes 80 mm apart. An axial flow fan with sleeves on either side of fan casing was designed and fabricated to supply a pre- determined air velocity over the entire length of the nozzle boom. At three different forward speeds (0.5, 2.5 and 4.0 km/h) dye solution was sprayed on the crop by the tractor-mounted, air-assisted sprayer and conventional tractor mounted sprayers. Droplet size (NMD and VMD), uniformity coefficient, droplet density, percent area covered by droplet spots per square centimeter and bio-efficacy were studied. At a forward speed of 4.0 km/h, better uniformity coefficient (1.69) was obtained for the air-assisted sprayer as compared to the conventional sprayer (2.04). With the tractor-mounted air-assisted sprayer, droplet deposition on the underside of the leaves was in the range of 14 to 94 drops/cm^2 at different portions of the plant. At a forward speed of 4.0 km/h, the area covered by droplets on the underside of top, middle and bottom leaves were 1.11, 0.93 and 0.44 % for air-assisted sprayer but there was no droplet deposition by the conventional sprayer. Reduction in the number of whitefly adults was about 30 to 70 % more for tractor mounted air-assisted sprayer than that of conventional tractor mounted sprayer.

Introduction

Most of the Indian farmers use knapsack sprayers or tractor mounted hydraulic sprayers for spraying different crops. These hydraulic sprayers apply pesticides on upper canopy of the plants. The upper canopy of the plant foliage prevents sprayed droplets from reaching the lower leaves and especially from reaching underside of leaves (Manor et al, 1989). Pests such as aphids and white flies usually feed on the underside of the leaves and down into the plant canopy (Sumner and Herzog, 2000). Therefore, an efficient spray technology is most important in enhancing the effectiveness of pesticides. Optimum droplet size, droplet density and their uniform impingement to the target surface are needed to ensure an efficient pest control (*Singh et al*., 2000). Air-assisted systems are designed to increase effectiveness of pest-control substances, provide better coverage to underside of leaves, promote deeper penetration into crop canopy, and make it easier for small droplets to deposit on target, cover more area per load and reduce drift (Hofman and Solseng, 2001). The air stream also creates turbulence within the crop that improves deposition of spray material on the targets, which are normally inaccessible. However, to reduce the frequency of application, quantity of chemical and to obtain better coverage of chemicals on cotton crop, air-assisted sprayer attachment to tractors should become available to farmers.

Materials And Methods

Components of Sprayer

An air-assisted system was used to produce a continuous airflow, which consisted of an axial fan, its casing and ducts (**Fig. 1**). The axial fan was designed and fabricated to provide air at a required flow rate and pressure. Size of the impeller was 73 cm having hub of 32 cm and nine aluminum blades of 20.5 cm length. The angle of each blade at the base was 22 degrees and 6 degrees at the tip. There was provision to change the angle of the blade. The fan casing was made out of G.I. sheet. Fan casing was open from the top and, on the bottom of the casing, there were sideways circular air outlets of 46 cm diameter. On the air outlets of the fan casing, sleeves (ducts) of 46 cm diameter were fixed. Throughout the length of the sleeve (duct) 40 mm holes 80 mm apart were on the bottom side. The total length of the sleeves (ducts) plus casing width was 600 cm. A horizontal triplex pump (HTP) was used to generate pressure for the application of spray formulation. A boom of GI pipe having a diameter of 35 mm was used for nozzle mounting. Spacing between nozzles, its working pressure and height were 45 cm, 3.5 kg/cm^2 and 50 cm, respectively, for uniform spray distribution using a patternator. The nozzle boom was placed just bellow but slightly behind of the holes of the sleeves (**Fig. 2**). A 35 hp tractor of M/s Massey Fergusson was used to operate the sprayer.

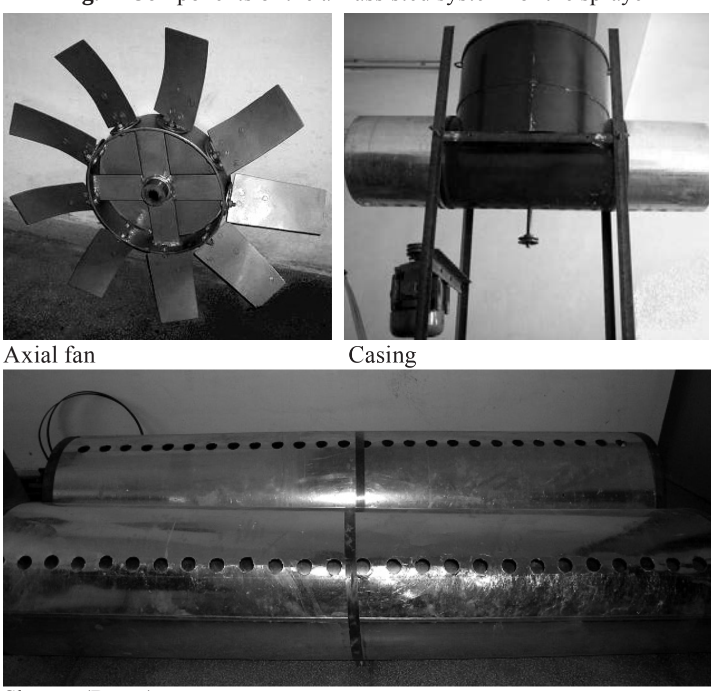
Evaluation Procedure

Plants were selected randomly in the field. Each selected plant was divided into three portions viz. top, middle and bottom. On both upper and under side of two leaves in each portion of the plants, cards (2.5 × 7.5 cm) of glossy paper were clamped. Dye (Methylene Blue MS) was mixed with water at 5g/l. The mixture was sprayed on the crop with the tractor-mounted air-assisted sprayer (**Fig. 2**). When sprayed dye dried, the cards were collected for further analysis. The procedure was replicated three times. Same procedure was repeated for three different rates of spray application. The results were compared with the results obtained for conventional tractor- mounted sprayer.

Droplet Size and Uniformity Coefficient

A computerized droplet analyzer was used for droplet analysis. The dye mixed with water and glossy paper for deposition measurement were the same as that used by Jain (2000). Therefore, the same spread factor was used for the calculation of number median diameter (NMD) and volume median diameter (VMD). The droplet spot diameters were separated into different ranges. Each range was assigned a mean spotted diameter. The mean diameter was divided by the spread factor of that range, which gave the

Fig. 1 Components of the air-assisted system for the sprayer



Axial fan Casing

Sleeves (Ducts)

Fig. 2 Tractor mounted air-assisted sprayer

mean diameter of the actual size of droplet of that range. With the number of droplets and droplet diameter for each range, volume contributed by droplets of the particular range was calculated. From the total volume contributed by the droplets, percentage of volume contributed by each range of droplet diameter and cumulative percentage of spray volume was calculated. Then, from the plot of cumulative percentage of spray volume and actual droplet diameter, the droplet size at which cumulative percentage of volume contributed reached 50 percent was taken as the VMD of the sprayed particles. From the total number of droplets, percentage of number of droplets and cumulative percentage number of droplets contributed by each range of droplet diameter were calculated. From the plot of cumulative percentage number of droplets and actual droplet diameter, the droplet diameter at which cumulative percentage number of droplets reached 50 percent was taken as the NMD of the sprayed particles. Uniformity coefficient (UC) was calculated by dividing VMD by NMD.

Droplet Density

By using adroplet analyzer, the number of drops in one square centimeter area of glossy paper was obtained on each card. The number of droplets per square centimeter was termed as droplet density.

Area Covered by Droplets

Each range of droplet size on the glossy paper was assigned a mean droplet diameter. With the number of droplets of each size in one square centimeter area and spotted diameter of those droplets, the area covered by droplets of a particular size was calculated as follows:

Area covered = (π / 4) × (spotted diameter of the drop)^2 × number of drops

A similar method was used for the calculation of area covered by the drops of other ranges and the sum of the area covered by the drops of all ranges in one square centimeter area gave the area of coverage per square centimeter of glossy paper.

Measurement of Bio-Efficacy of Spray

Two Methods were Used in this Study:

In one method each plot was divided into four quarters and in each quarter four plants were randomly selected. The number of adult whitefly on the three leaves in the upper canopy of each plant was counted 24 hours before spraying the insecticide. After 24 hours of spraying, a similar procedure of counting the adult whitefly was followed. The percentage reduction in the number of whitefly was termed as bio-efficacy of spray.

In the second method each plot was divided into four quarters and 25 fresh shed fruiting bodies were collected from each quarter. The number of the fruiting bodies damaged by bollworm was counted 24 hours before the spraying of insecticide and after 48 hours of the spraying. The percentage reduction in the number of damaged shed fruiting bodies was termed as Bio-efficacy of spray.

Results and Discussions

Droplet Size and Uniformity Coefficient

The volume median diameter (VMD) was 248.2 μ for the air-assisted sprayer and 279.7 μ for the conventional tractor mounted sprayer at a forward speed of 2.5 km/h (**Table 1**). At a forward speed of 4.0 km/h, the VMD for air-assisted sprayer was 261.3 μ and for the conventional tractor mounted sprayer it was 278.7 μ. At both the forward speeds (2.5 and 4.0 km/h) the VMD was larger for of conventional sprayer but the difference was low. The uniformity coefficient was the same (1.8) at forward speed of 2.5 km/h for both the sprayers. But, at the forward speed of 4.0 km/h better uniformity coefficient (1.69) was obtained for the air-assisted sprayer as compared to the conventional sprayer (2.04).

Droplet Density

Droplet densities on the underside of top, middle and bottom leaves were 49, 29 and 62 drops/cm^2, respectively, at a forward speed of 0.5 km/h for the air-assisted sprayer (**Table 2**). The droplet density on the under side of bottom leaves was more than that of top and middle leaves. This might have been due to the slow forward speed of the sprayer; the airflow had more time to push droplets down to the bottom section of the plants. The droplet density on the under side of top, middle and bottom leaves at a forward speed of 2.5 km/h were 94, 81 and 29 drops/cm^2, respectively, for the air-assisted sprayer. For the conventional sprayer on under side

Table 1 Droplet size and uniformity coefficient under field conditions

Sprayer	Forward speed (km/h)					
	2.5			4.0		
	NMD (μ)	VMD (μ)	UC	NMD (μ)	VMD (μ)	UC
Tractor mounted air-assisted	137.6	248.2	1.80	154.0	261.3	1.69
Conventional tractor mounted	155.2	279.7	1.80	137.0	278.7	2.04

of leaves at any portion of plants, it was negligible. When the air-assisted sprayer was operated at a forward speed of 4.0 km/h, the droplet density on the upper side of top, middle and bottom leaves were 171, 78 and 43 drops/cm^2, respectively, and for the conventional sprayer was 150, 115 and 49 drops/cm^2. Thus, for both the sprayers, the number of droplets deposited per square centimeter was more than desired. On the under side of top, middle and bottom leaves, deposition for the conventional tractor mounted sprayer was negligible but for the air-assisted sprayer deposition was 43, 23 and 14 droplets per square centimeter on the under side of top, middle and bottom leaves, respectively. Thus, the under side of the leaves of any plant position received an effective number of drops when air-assistance was provided with the sprayer, but without air-assistance the under side of leaves remained unsprayed.

Table 2 Effect of different parameters on droplet density under field conditions

Forward speed, km/h	Position in plant canopy		Number of drops/cm^2	
	Side of leaves	Section of plant	Air-assisted sprayer	Conventional sprayer
0.5	Upper	Top	-	-
		Middle	-	-
		Bottom	201	226
	Under	Top	49	4
		Middle	29	0
		Bottom	62	0
2.5	Upper	Top	154	222
		Middle	111	113
		Bottom	100	77
	Under	Top	94	0
		Middle	81	0
		Bottom	29	0
4.0	Upper	Top	171	150
		Middle	78	115
		Bottom	43	49
	Under	Top	43	0
		Middle	23	0
		Bottom	14	0

Table 3 Effect of different parameters on area covered by spots under field conditions

Forward speed, km/h	Position in plant canopy		Area covered by spots (mm^2/cm^2)	
	Side of leaves	Section of plant	Air-assisted sprayer	Conventional sprayer
0.5	Upper	Top	-	-
		Middle	-	-
		Bottom	10.04	13.06
	Under	Top	0.52	0.05
		Middle	0.75	0
		Bottom	1.64	0
2.5	Upper	Top	9.29	15.69
		Middle	6.50	7.53
		Bottom	5.75	5.11
	Under	Top	3.13	0
		Middle	3.76	0
		Bottom	1.43	0
4.0	Upper	Top	10.88	10.92
		Middle	4.30	6.54
		Bottom	3.40	2.53
	Under	Top	1.11	0
		Middle	0.93	0
		Bottom	0.44	0

Area Covered by Droplets

The area covered by droplets was 13.06 mm^2/cm^2 for the conventional sprayer and 10.04 mm^2/cm^2 for the air-assisted sprayer on the upper side of bottom leaves of the target surface when the sprayer was operated at 0.5 km/h (**Table 3**). For an air-assisted sprayer the area covered was 0.52, 0.75 and 1.64 mm^2/cm^2 on the underside of the top, middle and bottom leaves at a forward speed of 0.5 km/h. At this speed for the conventional sprayer 0.05 mm^2/cm^2 was on the under side of top leaves but negligible on under side of middle and bottom leaves. When the sprayer was operated at a forward speed of 2.5 km/h, the area covered by droplets on upper side of top, middle and bottom leaves was 9.29, 6.50 and 5.75 mm^2/cm^2 of the target surface when an air-assisted sprayer was used and for the conventional sprayer it was 15.69, 7.53 and 5.11 mm^2/cm^2. The area covered on the underside of the top, middle and bottom leaves was 3.13, 3.76 and 1.43 mm^2/cm^2 for air assisted sprayer but for the conventional sprayer the area covered by the droplets was negligible.

However, at a forward speed of 4.0 km/h, the area covered by the spray droplets on the upper side of top, middle and bottom leaves was 10.88, 4.30 and 3.40 mm^2/cm^2 for the air-assisted sprayer and for the conventional sprayer it was 10.92, 6.54 and 2.53 mm^2/cm^2. On underside of top, middle and bottom leaves, the area covered was 1.11, 0.93 and 0.44 mm^2/cm^2 for the air-assisted sprayer but there was no droplet deposition with the conventional sprayer.

Visual Observation of Spray Deposition

The spray deposition decreased on the upper side of leaves located at different sections of the plant for both the sprayers with an increase in forward speed (**Fig. 3**). Spray deposition on the upper side of the top and middle leaves appeared nearly similar, but on the upper side of the bottom leaves, spray deposition was more for air-assisted sprayer than conventional sprayer at each forward speed. It was also observed that the deposition on upper side of leaves at any forward speed decreased from top to bottom section of the plants. Moreover, the deposition on the upper side of the leaves on the bottom section was in excess at a forward speed of 0.5 km/h and at 4.0 km/h it was less on middle and bottom leaves. Deposition on the upper side of leaves of any section of the plants was better at a forward speed of 2.5 km/h. Almost negligible spray deposition was observed on the underside of top, middle and bottom leaves for the conventional sprayer but the air-assisted sprayer provided an effective deposition at each of the three forward speeds (**Fig. 4**).

Bio-efficacy

The average reduction in whitefly

Fig. 3 Spray deposition on upper side of top, middle and bottom leaves

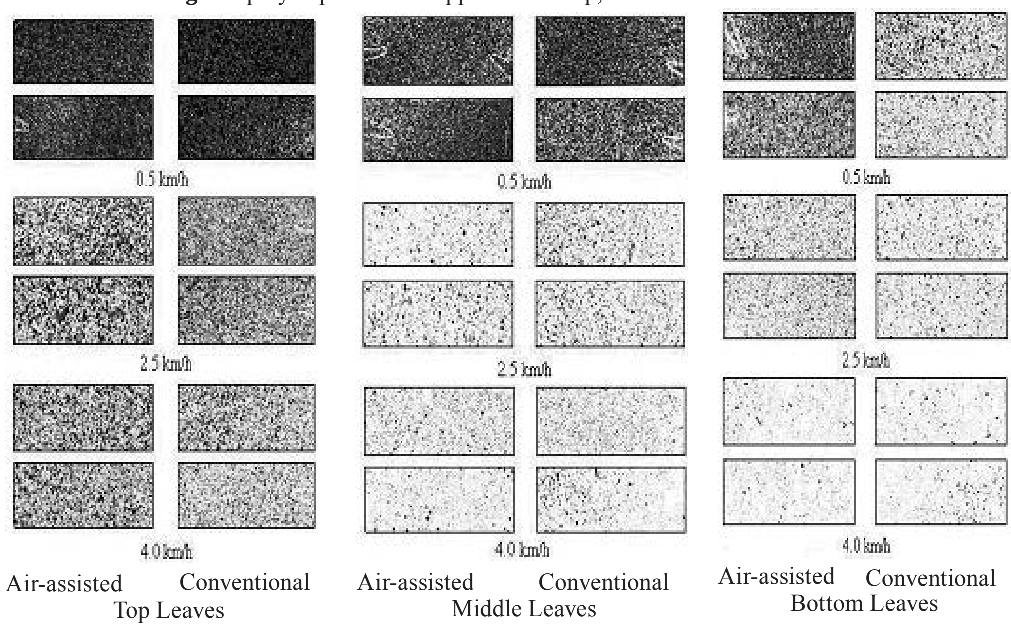
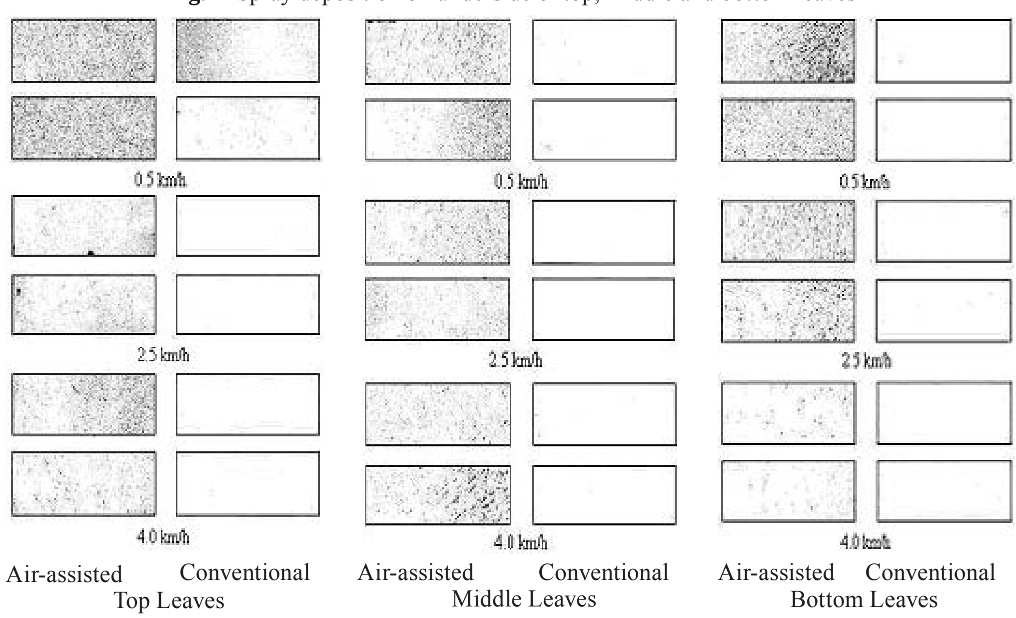


Fig. 4 Spray deposition on underside of top, middle and bottom leaves



was 61.5, 65.75 and 59.25 % after the first, second and third spray, respectively, for the air-assisted sprayer whereas it was 39.75, 38.75 and 45.75 % for the conventional sprayer (**Table 4**). The reduction in number of whitefly was 29.5 to 69.7 % more with the use of air-assisted sprayer as compared to conventional sprayer. The average reduction in freshly shed fruiting bodies after first, second and third spray was 30.00, 38.33 and 32.33 % for air-assisted sprayer but it was 16.00, 23.33 and 16.00 % for conventional sprayer.

Conclusions

1. The uniformity coefficient for tractor mounted air-assisted sprayer and conventional tractor mounted sprayer was almost the same at a forward speed of 2.5 km/h but at the forward speed of 4.0 km/h the uniformity coefficient for the air-assisted sprayer was better (1.69) than for conventional sprayer (2.04).
2. There was sufficient droplet deposition on the upper side of leaves of any section of the plant for both the sprayers.
3. Due to air-assistance, the sprayer was able to put an effective number of drops per square centimeter on the underside of leaves at any section of the plants.
4. The reduction in number of whitefly was 29.5 to 69.7 % more for air-assisted sprayer as compared to conventional sprayer. The reduction in freshly shed damaged fruiting bodies was 30 to 38.33 % for air-assisted sprayer where as for conventional sprayer it was 16 to 23.33 %.

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Table 4 Bio-efficacy (Percent reduction in the number of whitefly and percent reduction in freshly shed fruiting bodies)

Plot	First spray		Second spray		Third spray	
	Air-assisted sprayer	Conventional sprayer	Air-assisted sprayer	Conventional sprayer	Air-assisted sprayer	Conventional sprayer
A: Percent reduction in whitefly						
1	67	39	64	37	63	44
2	57	37	64	36	52	42
3	67	44	69	45	55	49
4	55	39	66	37	67	48
Average	61.5	39.75	65.75	38.75	59.25	45.75
B: Percent reduction in freshly shed fruiting bodies						
1	33	18	47	27	28	16
2	29	16	35	22	35	15
3	28	14	33	21	34	17
Average	30	16	38.33	23.33	32.33	16

Vibration Evaluation of Ginning and Pressing Machinery in Indian Cotton Ginneries

by

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Abstract

India has over 4,000 cotton ginneries in which thousands of workers toil under intolerable conditions. Cotton ginneries contain numerous types of machinery. Each is a source of noise and vibration. The basic machinery in a ginnery includes the double roller gin (DR), pre-cleaner, lint cleaner and baling press in addition to automatic material handling systems. The vibration levels were measured by vibration meter on the different commercial ginning machinery. The intensity of vibration for different parts of the double roller gin in terms of acceleration, velocity and displacement was varied between 3.29 and 47.85 m/sec^2, 0.25 and 5.85 cm/sec and 13 × 10^{-5} and 28.53 × 10^{-5} m, respectively. The coefficient of variation (CV) for acceleration was 48.8 % to 69.7 %. The maximum vibrations were observed on hopper, swing lever, gearbox and seed chute of the DR gin. The average acceleration, velocity and displacement for different models of the DR gin were 18.47 m/sec^2, 1.55 m/sec and 9.72 × 10^{-5} m with the corresponding CV values of 35.28 %, 16.06 % and 37.13 %, respectively. The average acceleration for pre-cleaner and lint cleaner was 5.48 m/sec^2 and 5.25 m/sec^2 with the corresponding CV values of 16.79 % and 21.26 %, respectively. The different parts of the baling press accelerated between 0.51 and 6.24 m/sec^2 with an average acceleration of 2.80 m/sec^2. The CV for different parts of the baling press was 74.78 %. The support columns of the press were more affected by vibrations followed by platform, power pack and lint condenser. The study showed that ginning machines were subjected to high vibrations, which were above the permissible limit. Hence, appropriate measures should be taken to bring down the level of vibrations to the acceptable level for the well being of the workers.

Introduction

India has over 4,000 ginneries which are dispersed all over the nine cotton-growing states. Out of these about 1,000 ginneries are being modernised with state of the art machinery under the Technology Mission on Cotton (TMC), Mini Mission IV (MM-IV). The major functions of a ginnery are to clean and gin the kapas, clean the lint and form a bale. The present ginneries can be categorized into three major groups based on the level of automation as conventional, semi-automatic and fully automatic. In these ginneries thousands of workers toil under intolerable conditions. Accidents, fires, dust and noise pollution and high machine vibrations are the potential sources of health hazards for gin workers. Cotton ginning systems contain numerous types of machinery; each a source of noise and vibration. The basic machinery in a ginnery is double roller gin (DR), pre-cleaner, lint cleaner and baling press. In a modernised ginnery, various kinds of conveying systems are being used for conveying of seed cotton, lint and seed from one processing stage to the other. These machines are designed, manufactured and installed without giving much importance to level of vibration, which is likely to cause health hazards to the workers. Also, no specific guidelines for laying foundations of these machines are followed.

The number of DR gins in a ginnery varies from 6 to 64 depending on the cotton arrival at the ginnery. On an average, a ginnery consists of about 18 DR gins. The beater of the DR gin reciprocates at the speed of about 1,000 strokes/min and the roller rotates a speed of about 100 rpm. Presently the gin manufacturers are more inclined towards increasing the length of the machine in order to increase the productivity of the DR gin but by sacrificing the life of the machine and operator's safety. More often the machines like pre-cleaner and lint cleaner are being installed on the floor without any foundation. These machines have 3 to 6 cylinders which rotate at a peripheral speed of about 7 m/sec. The baling press presses the loose lint into a bale of about 170 kg. The bale press is subjected to a load of about 400 tons while pressing the bale with hydraulic rams. High capacity centrifugal fans are used for pneumatic conveying of materials from one place to other. All these machines contribute to generate the vibrations which are unacceptable to the operator. The operators and labours working in the ginneries are subjected to large vibration causing them fatigue and physical discomfort. Exposure to high vibrations adversely affects their overall efficiency and safety. Unexpected breakdown of rotating machinery is the single largest cause of emergency downtime in industries. Equipment deteriorates as it is used and its vibration level usually increases accordingly. As a result vibration has been used as an indicator of equipment health condition. Effective prediction of equipment deterioration trend can help prevent equipment breakdown.

Vibration can be defined as oscillation of a mass about a fixed point. When the body comes in contact a mechanical source of vibration the tissues of the body become displaced from their resting position. In the work setting there are basically three types of vibrations that are significant to the workers. These include whole body vibration, segmental vibration and resonance. There are four physical factors of primary importance in determining the human response to vibration, namely, the intensity, frequency, direction and duration (exposure time) of the vibration. The intensity of vibration is generally described by acceleration, which is normally expressed in terms of m/s^2. The magnitude of vibration, that is acceleration, is expressed as a root mean squares (rms) value.

The effects of occupational hazards of vibrations in Indian cotton ginneries have never received attention. The Central Institute for Research on Cotton Technology (CIRCOT) has very recently conducted an ergonomic survey of Indian ginneries and a study on the vibration levels of the various machinery and workstations in the cotton gins. The objective of this study was to evaluate the vibration levels of different machinery used in cotton ginning systems in India and find the effect of vibration on workers health and suggest the possible ways to reducing the vibration levels.

Materials and Methods

The vibration levels were measured by using a vibration meter on the different commercial models of the double roller gin, pre-cleaners, lint cleaner and baling presses. Vibrations were measured in terms of accelerations (m/sec^2), velocity (cm/sec) and displacement (m). The vibration meter used for the measurement was Quest Technologies model VI-100. It was a battery operated, portable, hand held instrument and measured displacement, velocity and acceleration. The vibration meter had the frequency range of 5-10,000Hz. The Low and High ranges were provided for the vibration measurement.

Vibration levels of widely used makes and models of the double roller gin (DR1, DR2 and DR3) pre-cleaner (P1, P2, P3 and P4), lint cleaner (L1, L2, L3 and L4) and baling press were measured. Measurements were made on different parts of each machine that come in direct contact with the operator and are more prone to breakdown. Three replications were taken for each part of the machine. The vibration levels were measured under load and no load condition. The average of three replications was recorded as the vibration level for each part of the machine under study. Each machine was set and adjusted properly before taking the measurement. The data collected were analysed to find the average acceleration, velocity, displacement, standard deviation and coefficient of variation. The data were compared for different makes and models of ginning machinery. The measured vibration levels were compared with the standards values and appropriate measures were suggested to reduce the vibration to the acceptable levels.

Results and Discussion

Three different models of DR gins were studied for vibration measurement. Acceleration varied from 3.29 to 47.85 m/sec^2, velocity from 0.25 to 5.85 cm/sec and displacement from 13×10^{-5} to 28.53×10^{-5} m for different parts of DR gins. Hopper, swing lever, gearbox and seed chute vibrated more than the other parts of the gin (**Table 1**). These levels of vibration were above the tolerance limits of the operator. The average exposure time of operator on the DR gin was 15 min/hr. The coefficient of variation (CV) for acceleration varied from 48.8 to 69.7 %. Similarly, the CV for velocity and displacement was 18.87 to 110.1 % and 38.3 to 105.3 %, respectively. The high CV depicts the large variation in the vibration generated by different parts of the double roller gin machines.

Table 2 presents the comparative variations generated by different makes and models of DR gins. The mean level of acceleration, velocity and displacement was calculated for each model of the DR gin and was in the range of 12.22 to 25.23 m/sec^2, 1.27-1.73 m/sec and 9.31 × 10^{-5} − 9.99 × 10^{-5} m. The CV of acceleration for different DR gins was 35.28 %. The variations in vibration among different models were less compared to the vibration of different parts of the DR gin machine. The floor of the gin house vibrated at a mean acceleration of 0.56 m/sec^2.

Vibration measurements were made on different parts of four pre-cleaners. Acceleration varied from 0.88 to 14.33 m/sec^2 and velocity varied from 0.24 to 3.04 cm/sec for different parts of different models of pre-cleaners. Hopper and cylinder cover generated more vibrations. The CV for acceleration, velocity and displacement was from 56.56 to 79.3 %, 51.09 to 105.2 % and 46.73 to 109.2 %, respectively for different parts of cotton pre-cleaners (**Table 3**). The CV was more than 50 % for different parts of each model of pre-cleaner studied. It indicated that much improvement on design aspects of the pre-cleaner was required to reduce the variability of the vibrations and also to bring down the vibration to acceptable levels. Comparative level

Table 2 Comparison of vibrations of different makes of double roller gins

DR Gin	Mean Acceleration (m/sec^2)	Mean Velocity (m/sec)	Mean Displacement (m) × 10^{-5}
DR1	17.98	1.73	9.86
DR1	12.22	1.27	9.99
DR1	25.23	1.67	9.31
Range	12.22-25.23	1.27-1.73	9.31-9.99
Mean	18.47	1.55	9.72
STDEV	6.51	0.25	0.36
C.V. (%)	35.28	16.06	37.13

Table 1 Vibration measurements on different parts and makes of double roller gin

Machine Part	Acceleration (m/s^2)			Velocity (cm/s)			Displacement (m) 10^{-5}		
	DR1	DR2	DR3	DR1	DR2	DR3	DR1	DR2	DR3
Hopper	17.51	22.97	33.56	1.37	1.47	2.50	4.01	15.48	14.62
Gear box	23.92	14.60	32.58	1.80	1.66	1.79	11.78	8.79	9.38
Off side frame	8.04	4.99	13.19	0.25	1.18	0.60	2.72	8.36	1.42
Swing lever	15.88	18.33	47.85	0.55	1.11	1.75	2.26	9.68	8.34
Pressure weight	10.43	6.63	5.85	1.76	1.14	1.16	18.63	14.51	13.91
Seed chute	34.22	14.08	40.20	5.85	1.39	3.67	28.53	8.81	16.5
Electric Motor	15.92	3.29	3.39	0.59	0.97	0.28	1.13	4.33	1.02
Range	8.04-34.22	3.29-22.97	3.39-47.85	0.25-1.80	0.97-1.66	0.28-3.67	1.13-28.53	4.33-15.48	1.02-14.62
Mean	17.98	12.12	25.23	1.73	1.27	1.67	9.86	9.99	9.31
STDEV	8.79	7.36	17.59	1.91	0.24	1.15	10.39	3.83	6.23
C.V. (%)	48.8	60.7	69.7	110.1	18.87	68.9	105.3	38.3	66.9

Table 3 Vibration measurements on different parts and makes of cotton pre-cleaners

M/c Part	Acceleration (m/s^2)				Velocity (cm/s)				Displacement (m) × 10^{-5}			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Hopper	6.75	6.40	3.23	5.09	1.23	0.42	0.37	0.60	9.13	4.12	1.97	2.87
Cylinder- cover	4.05	5.31	8.37	6.89	0.75	0.73	0.33	0.82	7.57	7.97	2.00	2.93
Kapas-outlet	3.30	14.33	9.84	0.88	0.24	0.86	3.04	0.17	1.78	8.67	15.57	0.74
Trash- chamber	11.01	2.15	1.29	2.75	1.92	0.32	0.52	1.16	8.44	2.35	2.06	3.30
Motor	2.02	2.65	8.01	5.41	0.26	0.31	1.17	0.80	2.14	3.44	5.27	4.41
Range	2.02-11.01	2.15-14.33	1.29-9.84	0.88-6.89	0.24-1.92	0.31-0.73	0.33-1.17	0.16-0.82	1.78-9.13	2.35-7.97	2.00-15.57	0.74-4.41
Mean	5.42	6.16	6.14	4.20	0.88	0.52	1.08	0.71	5.81	5.31	5.37	2.85
STDEV	3.56	4.89	3.67	2.37	0.70	0.25	1.14	0.36	3.56	2.86	5.87	1.332
C.V. (%)	65.7	79.3	59.86	56.56	80.65	45.67	105.2	51.09	61.28	53.29	109.2	46.73

of vibrations for different models of pre-cleaner and their CV values are presented in **Table 5**. The CV values of acceleration, velocity and displacement were 16.79, 29.96 and 27.75 %, respectively. Less variation was observed among the different pre-cleaner models.

Four different models of lint cleaners were studied for vibration measurement. Acceleration varied from 1.34 to 8.82 m/sec^2, velocity varied from 0.11 to 2.35 cm/sec and displacement varied between 0.61 × 10^{-5} to 18.97 × 10^{-5} m for different parts of different models of the lint cleaner. Hopper and cylinder cover were found to vibrate more. **Table 4** shows the CV values for different parts and makes of lint cleaners. The CV values for acceleration were between 25.69 to 51.06 %. **Table 5** shows that the different models of lint cleaner have a CV of 21.26 % for acceleration, 39.72 % for velocity and 58.47 % for displacement. The average level of acceleration on the platform where the lint cleaners are mounted was 0.23 m/sec^2.

Vibration levels were also measured on different parts of a fully automatic cotton baling press. Measurements were made on different parts of the baling press such as lint condenser, press box, revolving tray, support column, power pack, platform, control panel and the floor. The different parts of the baling press accelerated between 0.51 and 6.24 m/sec^2. The support columns of the press were more affected by vibrations followed by platform, power pack and lint condenser. Acceleration near the press operator, i.e. on control panel, was 0.15 m/sec^2. The velocity varied from 0.03 to 1.35 m/sec. The platform supporting the condenser and made for catwalks during operation and repairs vibrated more. The displacement was maximum for the platform fol-

Table 6 Vibration measurement on different parts of a cotton baling press

M/c. Part	Acceleration (m/sec^2)	Velocity (m/sec)	Displacement (m) × 10^{-5}
Lint Condenser	1.76	0.33	5.17
Press Box	0.51	0.7	3.64
Revolving Tray	1.50	0.36	4.61
Support Column	6.24	0.57	4.25
Power Pack	2.57	0.16	3.30
Platform	4.23	1.35	10.76
Range	0.51-6.24	0.16-1.35	3.3-10.76
Mean	2.80	0.57	5.28
STDEV	2.09	0.42	2.76
C.V. (%)	74.78	73.14	52.22

Table 4 Vibration measurements on different parts and makes of lint cleaners

M/c Part	Acceleration (m/s^2)				Velocity (cm/s)				Displacement (m) × 10^{-5}			
	L1	L2	L3	L4	L1	L2	L3	L4	L1	L2	L3	L4
Hopper	7.35	8.82	8.82	1.77	0.32	1.33	0.84	0.11	3.35	17.77	6.56	0.61
Cylinder- cover	4.86	7.12	7.58	4.28	0.57	2.35	0.76	0.27	2.75	18.97	5.15	0.89
Kapas-outlet	1.47	1.34	6.66	5.30	0.12	0.16	0.76	0.34	0.79	0.95	7.43	0.92
Trash- chamber	3.17	5.78	6.39	6.47	0.91	1.16	0.34	0.39	3.23	7.43	2.24	2.10
Motor	5.79	4.58	4.14	3.46	1.16	1.24	1.43	1.54	9.86	7.00	8.70	8.99
Range	1.47-7.35	1.34-7.12	4.14-8.82	1.77-6.47	0.12-1.16	0.16-2.35	0.34-1.43	0.11-1.54	0.79-9.86	0.95-17.77	2.24-8.70	0.61-8.89
Mean	4.52	5.52	6.71	4.25	0.61	1.24	0.82	0.53	3.99	10.42	6.01	2.70
STDEV	2.28	2.82	1.72	1.78	0.42	0.77	0.39	0.57	3.43	7.70	2.47	3.56
C.V. (%)	50.43	51.06	25.69	42.04	68.78	62.23	47.27	108.3	85.98	73.91	41.14	131.8

Table 5 Comparison of vibration of different makes of pre-cleaner and lint-cleaner

Pre-cleaner				Lint Cleaner			
Pre-cleaner Model	Mean Acceleration (m/sec^2)	Mean Velocity (m/sec)	Mean Displacement (m) × 10^{-5}	Lint–cleaner Model	Mean Acceleration (m/sec^2)	Mean Velocity (m/sec)	Mean Displacement (m) × 10^{-5}
P1	5.42	0.88	5.81	L1	4.52	0.61	3.99
P1	6.16	0.52	5.31	L1	5.52	1.24	10.42
P1	6.14	1.08	5.37	L1	6.71	0.82	6.01
P1	4.2	0.71	2.85	L1	4.25	0.53	2.7
Range	4.20-6.14	0.52-1.08	2.85-5.81	Range	4.25-6.71	0.53-.1.24	2.7-10.42
Mean	5.48	0.79	4.83	Mean	5.25	0.8	5.78
STDEV	0.92	0.23	1.34	STDEV	1.12	0.31	3.37
C.V. (%)	16.79	29.96	27.75	C.V. (%)	21.26	39.72	58.47

lowed by condenser, revolving tray and support column. **Table 6** shows vibration levels for different parts of baling pres and corresponding CV values. The CV for acceleration of the baling press was 74.78 %. These high CV values would likely lead to unexpected breakdown during pressing because the baling presses were subjected to a huge load while pressing the cotton bale with the use of hydraulic rams.

Effects of Vibration on Workers

When the body comes in contact with mechanical vibration there is a direct adverse physiological effect on the body. The effect interferes with work efficiency and in some situations can put the workers at risk for injury. When the muscles of the body are exposed to vibration they react by exhibiting a protective reflex. The reflex causes the muscles to contract and shorten resulting in an increase in energy consumption. These sustained static muscles contractions result in a rapid fatiguing of the muscle. Fatigued muscles are more susceptible to injury.

In ginneries, it was observed that workers are not coming in continuous contact with the ginning machineries for more than 10-15 minutes in an hour. In these cases the permissible limit for vibration in terms of acceleration was 3.0 m/sec^2. Most of the parts of double roller gin, pre-cleaner and lint cleaner vibrate at acceleration above this permissible limit. These large vibrations may be because of crude and unscientific design of ginning and pressing machines, no specific guidelines for laying the foundation and no periodic maintenance.

Measures for Reduction of Vibrations in Cotton Ginneries

Excessive vibrations can be avoided by keeping machinery properly maintained and by properly making the foundation. The supporting structures or platforms made for mounting of pre-cleaners, lint cleaners or lint condensers and baling press should be properly designed. The eccentric parts of the machine might be redesigned. Loose fittings parts of the machines should be avoided. Hanging parts of the machines vibrate more and hence, should be redesigned and replaced. The machines should be made more compact.

Sources of vibration should be eliminated or minimized as much as possible. Workers should avoid continuous contact with a vibrating surface. Workstations should be designed in such a way that controls do not come in contact with vibrating surfaces. The workstations should be isolated from the source of vibration. Anti-vibration gloves should be used and the workers should not be exposed to more than 10 minutes of continuous use per hour if acceleration exceeds 3.0 m/sec^2.

To achieve safety, the workers have a responsibility to follow safe and healthy work practices; workers should be safety conscious and must avoid unsafe acts and practices. Factory owners must endeavor to rectify unsafe working conditions. Proper medical care should be provided to all employees. Safety and health instructions should be given to the workers as often as necessary during the ginning season. The manufacturers and ginners should come forward and try to minimize the levels of machine vibration for the well being of the operator, to avoid unexpected breakdown and to avoid the downtime.

Conclusions

1. The average acceleration, velocity and displacement for different models of DR gin were 18.47 m/sec^2, 1.55 m/sec and 9.72×10^{-5} m with the corresponding CV values of 35.28 %, 16.06 % and 37.13 %, respectively.
2. The average acceleration for pre-cleaner and lint cleaner was 5.48 m/sec^2 and 5.25 m/sec^2 with the corresponding CV values of 16.79 % and 21.26 %, respectively.
3. The different parts of the baling press accelerated between 0.51 and 6.24 m/sec^2 with an average acceleration of 2.80 m/sec^2. The CV for different parts of the baling press was 74.78 %.
4. Ginning machinery was subjected to high vibrations that were above the permissible limit. Hence, appropriate measures should be taken to bring down the level of vibration to the acceptable level for the well being of the workers.

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Technical Evaluation of the Agricultural Tractor Park of Chile

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Abstract

The principal objectives of this work were to identify the agricultural production systems of Chile, to establish the tractor hours demanded by these systems, to compare this demand with the actual tractor park and the total power available for agriculture; and to analyze the mechanization level indicators of Chilean agriculture.

The main sources of information were the VII National Agricultural Census of 2007, the Ministry of Agriculture, the Institute of Agricultural Research (INIA), the Office of Studies and Agricultural Policies (ODEPA), the Center for Information on Natural Resources (CIREN-CORFO), the Machinery Importers Association, agricultural mechanization experts of Chilean universities and managers of agricultural enterprises in Chile.

The agricultural production systems; the cultivated area with the 30 main crops including annual, perennial (fruit trees), horticultural and pastures; the tractor hours demanded by these Systems; and the human, animal and tractor power available were established. The mechanization level indicators obtained were compared with levels recommended for countries with emerging economies and with the levels existing in other South American countries.

The results showed that the total cultivated area of Chile corresponds to 1,900,735 hectares, of which 61.58 % corresponds to annual and perennial crops and 38.42 % corresponds to seeded and improved pastures. There are also 12.1million hectares of natural pastures. Perennial crops have a tractor hour demand 1.37 times that of the annual crops; seeded pastures on the other hand demand 7.75 times more tractor hours than improved pastures.

The actual tractor park of 53,915 units provides 2,459,502 kW. When human and animal power are added, a grand total of 3,194,778 kW is reached. This power does not appropriately cover the present demand of Chilean agriculture and a deficit equivalent to 1,686 tractors was established. In order to cover this deficit, an increment in the tractor import rate to 2,000 per year during a 3 to 4 year period would be needed.

The main agricultural mechanization level indicator of Chile is 1.29 kW per cultivated hectare. Other indicators include 40 cultivated hectares per tractor and only 9 rural persons per tractor. All these indicators are better than those of other

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South American countries.

Introduction

At the farm, enterprise, region and country levels there must exist a harmonical relationship between the work capacity and costs and between the tractor and machinery demands of the production systems and their availability. Over mechanization causes an increment of the fixed costs, lower profitability and bigger rural unemployment. On the other hand, submechanization with insufficient power and machines causes lack of opportunity in the execution of agricultural operations, reduction of the cultivated area and lower yields and production, all of which will lower profitability (Beduschi, 1996; Binswanger and Donovan, 1997; Gifford, 1996; Hetz and Esmay, 1986; Hunt, 1997; Jasmen, 1986).

Several authors (Clarke, 1997; FAO, 2001; Gifford, 1996; Rijk, 1989; Jasmen, 1986) have pointed out that the developing countries should have an agricultural mechanization strategy, as part of their rural development policy in order to avoid the problems associated with a "let it happen" attitude, which may cause over and submechanization.

The economic justification of tractors with their implements and machines, through the determination of the minimum hours of annual use and the planning of their utilization as the agricultural season progresses, should always form an important and integral part of the good management of a mechanized system (Beduschi, 1996; FAO, 2001; López and Hetz, 1998; Witney, 2005)

Commonly used agricultural mechanization level indicators include the quantity of tractors a country, region or enterprise has, the number of agricultural workers per tractor, the number of cultivated hectares per tractor, and the effective power available for each cultivated hectare. The first indicator does not say much if it is not associated with the cultivated and potentially cultivated area. The workers per tractor indicate, in a very general manner, the rurality of the population. The range of hectares per tractor could reasonable lie between 30 to 150 according to the tractor power, the intensity of the crops rotation, the time available to carry out the operations, and to the profitability of the activity (Hunt, 1997; Witney, 2005; Clarke and Bishop, 2002; FAO, 2001; Jasmen, 1986).

The best indicator is, without a doubt, the effective power (kW) per cultivated hectare (ha). A study by Giles (1975), with data from the 1960's, showed that there was a very strong yield response to power up to 0.6-0.7 kW/ha, and that, once this power level is reached, it would be preferable to increase high yielding inputs of an Agronomy of excellence, like certified seeds, irrigation, fertilizers and pesticides. More recently, several authors (*Rasooli*, 2008; *Clarke* and *Bishop*, 2002; *Donato de Cobo et al*., 1999; *Binswanger* and *Donovan*, 1997; *Clarke*, 1997; 1995; *Fluck*, 1992; *Stout*, 1990) have indicated that the productivity of land and labor could be greatly increased to insure food security if the developing countries could reach mechanization levels of 1.0 to 1.2 kW per hectare of cultivated land.

For Chile, the Production Development Corporation (CORFO, 1969) produced a mechanization diagnostic for 1963 with data from the type of agriculture practiced during the 1950's, reaching some conclusions that are not pertinent at the current time. Later an analysis of Chilean agriculture, in order to propose the basis for a national agricultual mechanization policy (never implemented), was carried out by Jasmen (1986). Also, a technical evaluation and a study of prices and costs of the more than 100 tractor models sold in the country were carried out (*Hetz et al*., 1998; *Hetz* and *Weinlaub*, 2001). In the 1980´s a preliminary study by Hetz (1986) about the needs and availability of agricultural machines in Chile was performed; however, that study did not separate Chilean agriculture by species and cultivated areas working instead with three large blocks of activities and finding an important tractor deficit.

The objectives of this work were to identify the main agricultural production systems in Chile, to establish the tractor hours demanded by these production systems, to compare this demand with the actual tractor park and other sources of energy and to analyze the mechanization indicators of Chilean agriculture.

Methodology

Information Sources

The main sources of information were the VII National Agricultural Census of 2007, the Ministry of Agriculture, the Institute of Agricultural Research (INIA), the Office of Studies and Agricultural Policies (ODEPA), the Center for Information on Natural Resources (CIREN-CORFO), the Machinery Importers Association, agricultural mechanization experts of Chilean universities and managers of agricultural enterprises.

Production Systems and Cultivated Area

The 15 most important annual crops and the 15 most important perennial crops (fruit orchards and vineyards) according to the planted area were selected from the results of the 2007 national agricultural census (INE, 2008), and their specific production systems were established. The crops with smaller planted areas were joined together and included as other crops.

Tractor Hours Demanded

In order to establish this demand the operative time (h/ha) of each one of the agricultural operations was determined according with the data collected from the literature (Witney, 2005; Ibáñez and Abarzúa, 1998; López and Hetz, 1998; Hetz et al, 1998; Hunt, 1997) and the standards developed and agreed upon through interviews with the mechanization experts. To estimate the h/ha for the perennial crops, the useful life (commercial) of the orchard was used to distribute the h/ha needed for the orchard establishment in the years of useful life. To seeded and improved pastures, 6 h/ha and 2 h/ha were assigned, respectively (Ibañez and Abarzúa, 1998).

Estimation of Power Available

Human power was estimated considering a percentage of the population between ages 15 to 60 years, in the following manner: 20 % for ages 15 to 20 and 40 % for ages 21 to 60. The power equivalents were: 0.05 kW for women and 0.075 kW for men, considering 100 % for ages 20 to 60 and 90 % for ages 15 to 20 years (Fluck, 1992; Stout, 1990).

Animal power was estimated considering 30 % of bovines, 40 % of horses and 10 % of mules and donkeys (INE, 2008). The power equivalents used were: 0.75 kW for horses, 0.55 kW for oxen, 0.45 kW for mules and 0.25 kW for donkeys (Fluck, 1992; Stout, 1990).

Tractor power was estimated by classifying them into three groups according to their age and average effective power as follows: 70 kW were assigned to tractors up to 5 years old, 50 kW were assigned to tractores from 6 to 15 years old, and 22 kW were assigned to tractors older than 15 years (Hetz and Weinlaub, 2001; INE, 2008). An average annual use of 500 hours was utilized (Jasmen, 1986).

Evaluation of the Demand and Availability of Power for Agriculture

This evaluation was carried out by comparing the tractor hours demanded by Chilean agriculture with the capacity to satisfy it with the actual tractor, human and animal power available. The power available per cultivated area (kW/ha) with the mechanization levels proposed for countries with Chile´s level of development were compared. Also general mechanization indicators such as hectares per tractor and rural population per tractor were compared with those of other South American countries.

Table 1 Agricultural area of Chile considered in this study (INE, 2008)

Soil use	Area (ha)	%	Main crops
Annual crops	717,103	37.7	Cereals, legumes, tubers, roots, vegetables, industrial
Perennial crops	453,272	23.9	Vineyards, fruit orchards
Seeded pastures	530,360	27.9	Alfalfa, clovers, grasses, other species
Improved pastures	200,000	10.5	Native grass species, some legumes
Total	1,900,735	100.0	

Table 2 Main annual crops in Chile (INE, 2008)

Species (Scientific name)	Seeded area (ha)	% of total area
Wheat (Triticum spp)	230,380	32.1
Maize (Zea mays L.)	103,435	14.4
Oats (Avena spp)	81,752	11.4
Potatoes (Solanum tuberosum L.)	53,780	7.5
Rice (Oryza sativa L.)	22,746	3.2
Sugarbeet (Beta vulgaris)	20,914	2.9
Lupines (Lupinus spp)	20,652	2.9
Triticale (Triticosecale Wittmack)	19,924	2.8
Barley (Hordeum spp)	18,500	2.6
Beans (Phaeolus vulgaris)	16,785	2.3
Tomatoes (Lycopersicon esculentum)	13,630	1.9
Rapeseed (Brassica napus L.)	11,312	1.6
Lettuce (Lactuca sativa L.)	7,027	1.0
Squash (Cucurbita spp)	6,323	0.9
Onions (Allium cepa L.)	6,130	0.9
Others*	83,813	11.7
Total	717,103	100.0

*Includes peas, lentils, tobacco, sunflower, chickpeas, garlic, broadbeans, cabbage, cauliflower, strawberry, melon, watermelon, red dwarf peppers, and other vegetables

Table 3 Main perennial crops (fruit trees and bushes) crops in Chile (INE, 2008)

Species (Scientific name)	Area planted (ha)	% of total area
Vineyards* (Vitis spp)	191,402	42.2
Avocado (Persea americana)	39,302	8.7
Apple (Malus domestica)	37,197	8.2
Plum (Prunus domestica)	18,957	4.2
Peach (Prunus persica)	16,750	3.7
Olive (Olea europea)	16,520	3.6
Walnut (Juglans regia)	14,584	3.2
Cherry (Prunus avium)	13,461	3.0
Blueberry (Vaccinium spp)	10,762	2.4
Kiwi (Actinidia deliciosa)	9,949	2.2
Orange (Citrus sinensis)	9,805	2.2
Lemon (Citrus limon)	8,002	1.8
Almond (Prunus dulcis dulcis)	7,716	1.7
Raspberry (Rubus ideaus)	7,550	1.7
Pear (Pyrus communis)	6,882	1.5
Other fruit trees**	44,433	9.8
Total	453,272	100.0

*Includes table, wine and pisco grapes
**Includes quince, apricot, grapefruit, cherimoya, prickly pear, medlar, other fruit trees and bushes

Results and Discussion

Areas and Species Considered in this Study

According to INE (2008) the agricultural area utilized in Chile covers 1,900,735 hectares, of which 717,103 ha correspond to annual crops, 453,272 ha to permanent crops, 530,360 ha to seeded pastures and 200,000 ha to improved pastures, as is shown in **Table 1**. The 1.9 million ha being utilized at present do not agree well with the 5.2 million ha of Arable Soils Classes I to IV existing in Chile according to Perez and Gonzalez (2001), Soto and Ulloa (1997), SAG-ODEPA, (1968). It is known that part of the difference can be explained by fallow land, forestry plantations, the growth of cities and roads, but it does not explain appropiately all the difference.

To the 1.9 million ha of annual and perennial crops and pastures, 12.1 million hectares of natural pastures should be added; this large area is not receiving mechanized agronomic management practices at the present time.

Tables 2 and **3** show the different species and area covered by the 30 principal annual and perennial crops. The main annual crops are wheat, maize and oats which account for 57.9 % of the area; on the other hand, vineyards, avocado and apple trees are the main perennial crops covering 59.1 % of the area.

Energy Demand of the Production Systems

Table 4 shows that the total power demand of the annual crops reaches 11,486,747 tractor hours per year, of which 51.6 % is utilized in wheat, maize, oats and potato production. Among the crops that use the most h/ha are tomatoes, sugarbeet and potatoes with more than 20 hours, most of which are used for weed and pest control. The crops that have the smallest demand are no-till wheat and tricale, with only 7.3 h/ha and 9.1 h/ha, respectively.

On the other hand, **Table 5** shows that the total power demand of the perennial crops reaches 15,820,311 tractor hours per year, of which 51.5 % corresponds to wine and table grapes, avocado and apple produc-

Table 4 Mechanized operations of the 15 main annual crops in Chile

Crops	Total ha	Mechanized operations, h/ha									Total	Hours/ year
		Soil preparation					Crops maintenance					
		Plow	Disc Harrow	Teeth and roller harrow	Furrow	Seeding	Pesticide appli\ cation[1]	Fertiliz[2]	Cultivador[3]	Harvest[4]		Total
Wheat	230,380											
Conventional	161,266	2.5	1.3		0.5	1.5	1.5	0.75		2.5	10.6	1,701,356
No till	69,114				0.5	1.5	2.0	0.75		2.5	7.3	501,077
Maize	103,435	2.5	1.3	0.75		1.5	3.0	2.00	2.4	3.5	17.0	1,753,223
Oats	81,752	2.5	1.3		0.5	1.5	1.5	0.75		2.5	10.6	862,484
Potatoes	53,780	2.5	1.3		1.0	2.0	3.0	0.75	3.6	6.5	20.7	1,110,557
Rice	22,746	2.5	1.3			1.5	3.0	0.75		4.0	13.1	296,835
Sugar beet	20,914	2.5	1.3	0.75		2.0	7.5	2.00	6.0	2.0	24.1	502,982
Lupines	20,652	2.5	1.3			1.5	3.0	0.75		3.5	12.6	259,183
Triticale	19,924	2.5	1.3		0.5		1.5	0.75		2.5	9.1	180,312
Barley	18,500	2.5	1.3		0.5	1.5	1.5	0.75		2.5	10.6	195,175
Beans	16,785	2.5	1.3	0.75	1.0	1.5	3.0	1.00	3.6	2.5	17.2	287,863
Tomatoes	13,630	2.5	1.3	0.75	1.0	2.5	7.5	2.60	3.9	6.0	28.1	382,322
Rapeseed	11,312	2.5	1.3	0.75	0.5	1.5	4.5	0.75		2.5	14.3	161,762
Lettuce	7,027	2.5	1.3	0.75	1.0	2.5	3.0	2.60	2.6	2.0	18.3	128,243
Squash	6,323	2.5	1.3	0.75	1.0		3.0	1.00	3.6	1.0	14.2	89,470
Onions	6,130	2.5	1.3	0.75	1.0		6.0	2.60	3.9	2.0	20.1	122,907
Others	83,813	2.5	1.3	0.75	1.0	2.5	6.0	2.60	3.6	2.5	22.8	1,906,746
National total	717,103											10,442,497
[5]National total + 10%												11,486,747

1 Two pesticide applications (1.5 h/ha × Number of applications)
2 Fertilization (0.75-1.3 h/ha × Number of applications)
3 Cultivator (1.2-3 h/ha × Number of applications)
4 Includes transportation of produce
5 Includes 10% for operations carried out occasionally, such as inputs and produce transportation

Table 5 Mechanized operations of the 15 main perennial crops (trees, bushes) in Chile

Crops	Total ha	Mechanized operations, h/ha								Total
		Crops establishment		Commer-cial life, years	Total h/ha	Crops maintenance				h/year
		Soil prepa-ration[1]	Furrow/ ridge			Herbicide applic.[2]	Pesticide appli-cation[3]	Harvest transpor-tation[4]	Total h/ha	
Vineyards	191,402									
Wine	118,488	5	2.5	25	0.30	6	12	8	26.00	3,116,234
Pisco	10,504	6	2.5	25	0.34	6	12	8	26.00	276,675
Table	62,410	5	1.5	20	0.33	6	12	14	32.00	2,017,403
Avocado	39,302	4.5	5	35	0.27	13	18	10	41.00	1,622,050
Apple	37,197	4.5	2	25	0.26	6	10	21	37.00	1,385,960
Plum	18,957	4.5	2	15	0.43	6	13	15	34.00	652,753
Peach	16,750	4.5	2	15	0.43	6	21	16	43.00	727,508
Olive	16,520	5.6		15	0.37	2.5	16	24	42.50	708,267
Walnut	14,584	4.5	1.5	30	0.20	6	13	2	21.00	309,181
Cherry	13,461	4.5	2	20	0.33	6	9	10	25.00	340,900
Blueberry	10,762	4.5	5	20	0.48	7	11	2	20.00	220,352
Kiwi	9,949	4.5	2	20	0.33	6	3	12	21.00	212,162
Orange	9,805	4.5	2	30	0.22	13	18	10	41.00	404,129
Lemon	8,002	4.5	2	30	0.22	13	18	10	41.00	329,816
Almond	7,716	4.5	5	20	0.48	7	11	2	20.00	154,586
Raspberry	7,550	4.5	2	25	0.26	6	9	1	16.00	125,462
Pear	6,882	4.5	2	25	0.26	6	10	21	37.00	256,423
Other fruit trees	44,433	4.5	2	25	0.26	6	13	15	34.00	1,522,240
National total	453,272									14,382,101
[5]National total + 10%										15,820,311

1 Soil preparation includes plowing and harrowing
2 Aherbicide application (3 applications × 2 h/ha)
3 Pesticide applicación, depends on the crop (1 to 2.5 h/ha × Number of applications)
4 Harvest tansportation (1h/ha × (Number of bins/6 bins per wagon))
5 Includes 10 % for operations carried out occasionally, such as frost control, bush and tree clearing.

Table 6 Total yearly demand of tractor hours in Chile

Soil use	Area (ha)	Demand h/year %		Human and animal operations (10%)*	Tractor hours per year**
Annual crops	717,103	11,486,747	37.2	1,148,675	10,338,072
Perennial crops	453,272	15,820,311	51.2	1,582,031	14,238,280
Seeded pastures	530,360	3,182,160	10.3	318,216	2,863,944
Improved pastures	200,000	400,000	1.3	40,000	360,000
Total	1,900,735	30,889,218	100.0	3,088,922	27,800,296

*Carried out by human and animal power, ** To be carried out by tractor power

Table 7 Agricultural tractor park of Chile (INE, 2008)

Age (years)	Tractors		Average power** (kW)	Power available**	
	Units*	%		(kW)	%
< 5	7,173	13.3	70	502,110	20.4
6 to 15	33,181	61.5	50	1,659,050	67.5
> 15	13,561	25.2	22	298,342	12.1
Total	53,915	100.0		2,459,502	100.0

* INE, 2008 ** Elaborated by the authors

tion. Among the crops that use the most h/ha are peach, olive, avocado, orange and lemon with more than 40 hours, with most of them also used for weed and pest control. The crops that have the smallest demand are raspberry with 16 h/ha and blueberry and almond with 20 h/ha each.

In **Fig. 1**, which shows the percentage distribution of the total yearly demand of tractor hours of the agricultural production systems, it can be seen that perennial crops use 51 %, annual crops use 38 %, seeded pasture use 10 % and improved pastures use 1 %.

Total Yearly Demand of Tractor Hours

Table 6 shows that the tractor hours demand of the annual and perennial crops reaches 11,486,747 and 15,820,311 h/year, respectively; when the demand of the pastures is added, a grand total of 30,889,218 h/year appears. When the energy provided by humans and animals is substracted, the demand that should be provided by tractors comes to 27,800,296 h/year.

Table 8 Total power available for agriculture in Chile by sources

Source	Power (kW)	% of total power
Human	29,482	1
Animal	705,794	22
Tractor	2,459,502	77
Total	3,194,778	100

Table 9 Demand and supply of tractor hours and tractor deficit in Chilean agriculture

Cultivated area* Ha	Total demand h/year	Human & animal supply 10%	Tractor hours demand h/year	Tractor annual use h/year	Tractors required	Existing tractors	Tractor deficit
1,900,735*	30,889,218	3,088,922	27,800,296	500	55,601	53,915	−1,686

* Includes annual and perennial crops, seeded and improved pastures

Table 10 Mechanization indicators of several countries in South America

Country	kW/ha	ha/tractor	Rural population/tractor
Argentina	0.60	n.i.f.	13
Bolivia	0.09	522	596
Chile	1.29	40	9
Colombia	0.23	216	417
Ecuador	0.30	419	209
Peru	0.14	319	593
Venezuela	0.79	69	47

Fuentes: FAOSTAT, 2008; Reina and Hetz, 2008; Donato de Cobo et al, 1999. n.i.f. = no information found

Fig. 1 Percentage distribution of the yearly demand of tractor hours in Chile

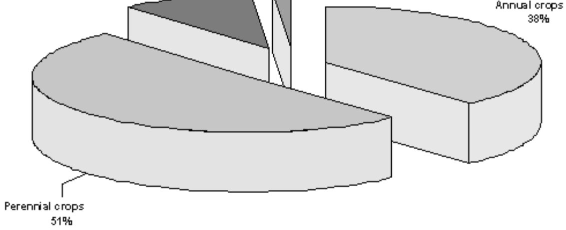
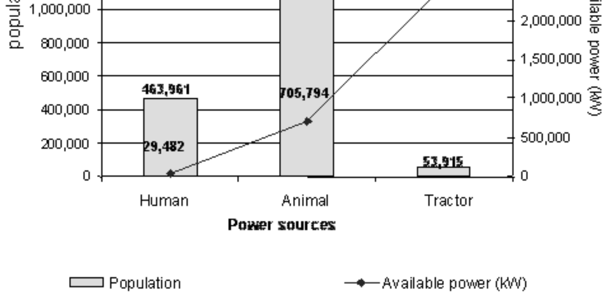


Fig. 2 Power supply to agriculture in Chile



Agricultural Tractor Park and Power Supply by Sources to Agriculture

Table 7 shows the characteristics of the tractor park of Chile. There is a total of 53,915 tractors of which the majority (61.5 %) are from 6 to 15 years of age; there is also a large group (25.2 %) with more than 15 years of age, which makes them unreliable. All of them provide 2,459,502 kW of power.

Table 8 and **Fig. 2** show that when the power supplied by humans and animals is added, a grand total of 3,194,778 kW is reached. Of the power supplied by humans, 64 % is provided by men. Of the power supplied by animals, 87 % corresponds to oxen. The numbers in **Table 8** and **Fig. 2** demonstrate that the large majority of power is provided by tractors, especially those from 6 to 15 years of agem which provide 52 % of the grand total.

Demand and Supply of Tractor Hours and Tractor Excess/Deficit

Table 9 shows that the demand of tractor hours of the area with annual and perennial crops and seeded and improved pastures (1,900,735 ha) is 30,889,218 h/year. When the work carried out by humans and animals (10 %) is substracted, the hours that should be provided by tractors comes down to 27,800,296 h/year. These numbers translate into a deficit equivalent to 1,686 tractors.

Moreover, considering the steady increment of the irrigated area in the last three decades, the area that will be irrigated by the new projects already being carried out, the 12.1 million ha of natural pastures that are not receiving agronomic management practices at present, and the unaccounted for 3 million hectares from what is being used at present to the 5.2 million hectares of arable soils, it is clear that Chile has a tractor deficit. To cover the actual deficit of 1,686 tractors and considering the historical mean annual rate of tractor importation into Chile of 1,500 aproximately, a steady increment of the import rate to 2,000 tractors per year, during a 3 to 4 year period, would be needed.

Mechanization Indicators of Chilean Agriculture

Table 10 shows agricultural mechanization indicators for several countries in South America. Chile compares very well with the other countries, having 1.29 kW per cultivated hectare, 40 ha per tractor and only 9 persons per tractor living in the rural area. These values are much higher than those for Bolivia, Colombia, Ecuador and Peru.

Conclusions

The productive systems of Chilean agriculture cover 1.9 million hectares of which 37.7 % correspond to annual crops, 27.9 % to seeded pastures, 23.9 % to perennial crops, and 10.5 % to improved pastures. There are also 12.1 million hectares of natural pastures.

The total energy demand of Chilean agriculture reaches 30.9 million tractor hours per year, of which 51.2 % correspond to perennial crops, 37.2 % to annual crops, 10.3 % to seeded pastures, and 1.3 % to improved pastures. The natural pastures are not receiving agronomic management practices at present.

The actual agricultural tractor park has 53,915 units that provide 2,459,502 kW. Adding the power provided by humans and animals a grand total of 3,194,778 kW is reached. This power does not appropriately satisfy the total demand of tractor hours, and a deficit equivalent to 1,686 tractors appears.

The mechanization indicators of Chilean agriculture have reached the values proposed for countries with Chile's level of development and are slighty better than those of the majority of the other South American countries, especially the 1.29 kW per cultivated hectare and the 40 cultivated hectares per tractor.

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ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

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Evaluation Of An Handy Tool For Sugacane Detrashing:

G.Kathiresan, Professor (Agronomy), Sugarcane Research Station, Tamil Nadu Agricultural University, Sirugamani-639 115,Tamil Nadu, INDIA.

De-trashing is the removal of dried, yellowish green, bottom leaves in sugarcane crop. This single operation has several advantages that it reduces the pest menace like inter node borer, white flies, mealy bugs, scales and pyrilla and can remove the sprouted buds in the cane stalk. Behind this, aeration and sanitation of the cane field can be improved and it reduced the rodent and reptile problems also. This can improve the cane yield and quality.

Earlier, labourers have done de-trashing, particularly by women labours. The drudgery involved in this operation make the labourers not to come for the work. Though, several advantages are there, farmers unable to do this operation due to unavailability of labours. If any tool which facilitates this operation is much useful to the cane farmers. Hence, this tool (Sugarcane de-trasher ? Karumpuk kathi) was designed in such a way to improve the labour's efficiency by decreasing drudgery facing by them. This is a tool, which has just two knives fitted in 'U' shaped mild steel flat that moves side ways with tension. There is no complex technology involved here for operation also easy to carry.

■■

Field Performance Evaluation of Manual Operated Petrol Engine Powered Weeder for the Tropics

by
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Abstract

A manually operated engine powered rotor-weeder for delta region with a 1.4 hp petrol engine was designed and fabricated. The field performance was evaluated and compared with the performance of a traditional manual hand hoe. The weeder consists of main frame, handle rotary blades, shaft, sprocket and chain, chassis, cutting depth hint rear cutting depth adjuster, wooden engine sitting, engine and ground wheel. The theoretical field capacity of the rotor-weeder was 0.47 ha/hr with an effective field capacity of 0.34 ha/hr, which was approximately twenty times that of manual weeding. The performance index was 1,700 and fuel consumption was 3.2 litres in 8 hours time. The rotor-weeder had a weeding efficiency of 71 % for removing shallow-rooted weeds. This suggested that the engine powered weeder could be useful equipment in modernizing agriculture for small farm holders.

Introduction

The effectiveness or the efficiency with which the machine performs its intended function is considered in evaluating the performance of an implement. The machine should be adapted to the soil and environmental conditions of the farm. All machines are designed to perform a given task at a specified time. If this designed objective is not met it means that the machine and the power unit is not correct according to Keperer et al. (1978) as cited by Yohanna and Ifem (2004).

Weeds grow in places where they are not required and have constituted many problems to agricultural practices particularly in the tropical region of the world. They remain the most important crop production constraint, competing seriously with crops for soil nutrients, light and moisture, thereby, reducing productivity (*Mganilwa et al*., 2003). Weeds are detrimental to crop growth and consequently yield.

Weed control is a very expensive step in crop production; hence, a successful farmer strives to make judicious use of farm equipment in order to maximize production with minimum cost. The most commonly used technique in Nigeria is the mechanical method of weed control which includes the use of any mechanical device, hoe, weeder or cultivator.

Mechanical weed control not only kills the weeds between the crop rows but also keeps the soil surface loose, thus, ensuring better soil aeration and water intake capacity.

Weeding is inevitable for crop management in the tropical region. Thus, various weeding practices such as biological, chemical, cultural, thermal, mulch and mechanical weeding have been introduced with various levels of effectiveness. Research reveals that one-third of the cost of cultivation is being spent for weeding alone (*Rangasamy et al*., 1993). The problems usually associated with traditional methods of weeding practices are low efficiency and farmers bending over resulting in tremendous loss of energy. Most farmers are still operating the traditional methods of weeding by hand-hoeing with long handle-hoe, and cutlasses. This method is not only inefficient but also very low output, resulting in delay in handling large areas of cultivation.

Manual weeding operation is labour intensive subjects farmers to bending with the handle at 450 rake angle and leaves them in a back-breaking bending position (*Nkakini et al*., 2006).

Agricultural machine performance assessment is accomplished at the rate of operation and quality of the field out-put. Thus, the field machine performance is the rate at which it can finish a field operation while performing its intended functions or useful work.

Timeliness of farm operations is also a very important factor. It is the ability to perform an activity in such a time that the quality and quantity of the products are optimized. For accomplishment of this, it becomes essential that the tillage equipment have adequate capacity to enable the farmer to complete these operations within the time available. Machine performance is a function of rate of work or capacity, completeness of operation and quality of work done. This capacity is usually measured in hectares per hour. Taking the effective width used and all possible time losses into consideration, an effective capacity or actual field capacity is obtained, which is lower than the theoretical capacity. Therefore, the effective field capacity is the actual rate of land or weeding coverage in a given time based upon total field time. And, field time is that spend by a machine in the field measured from the start of a functional activity to the time the functional activity is completed (*Kaul* and *Nwuba* 1992, *Onwualu et al*., 2006).

Different machines give different field performances depending on the nature of their operations and the level of management. There was no recorded data available from operations under local conditions to be able to quantify the degree of field performance achieved in various weed operations in the tropics, hence the need to evaluate the field performance of a manually operated weeder for the tropic under field condition was essential. The performance of the weeders were affected by the type of weeding hoe and time of weeding.

Field efficiency is the ratio of the effective field capacity to the theoretical field capacity. It takes into consideration time losses as well as the inability to use the full width of machine. The theoretical field capacity (Fc_t), of an implement is the rate it performs its extended function if operated continuously at its rated width. It is the hectare covered per hour or rate of possible field coverage if the machine works all the time at the recommended speed and utilizes its entire width of operation. There is no allowance for loss of time in turning and servicing.

Madukavi *et al.* (1987) conducted a field study with different tillage tool treatment combinations and weed control treatment combinations. The results indicated that the primary tillage tools alone for controlling weeds were found ineffective and the treatment combinations of blade harrowing or tilling with hand weeding were found advantageous in effective weed control.

Khan and Diesto (1987) as cited by Rangasamy *et al.* (1993) reported the development of a push type cone weeder which uprooted and buried weeds in a single pass without requiring a back and forth movement, especially suitable for paddy.

Fanoll (1986) evaluated three models of shoulder suspended, hand-guided rotary power weeders in comparison with hand slashing of weeds, the power weeders were operated by 1.86, 1.49 and 1.12 kW gasoline engines. The field capacities of the machine were 12 to 13 hectares per hour higher than the hand weeding process. The weights of these machines ranged from 5.4 to 10 kg with overall lengths, 1,600 to 1,700 mm. The engine characteristics were 2 stroke, single cylinder 50.2, 35.0 and 27.2 cc displacements, flywheel, magneto -ignition, petrol operated 8 : 1 compression ratio and air-cooled. Out of the three models tried, the 1.4 kw machine had better performance in terms of both field capacity and weeding cost.

The cost of weed management is enormous; however, the opportunity cost of weed management is higher. Rangasamy *et al.* (1993) reported that one third of the total cost of cultivation is spent on weeding.

Rangasamy *et al.*(1993) as cited by Kamal and Babatunde (1999) devel-

Fig. 1 Autographic view of the component parts of the Roto Weeder

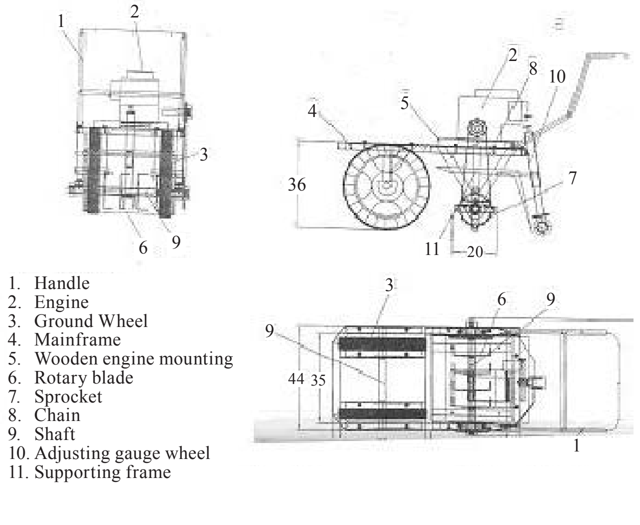
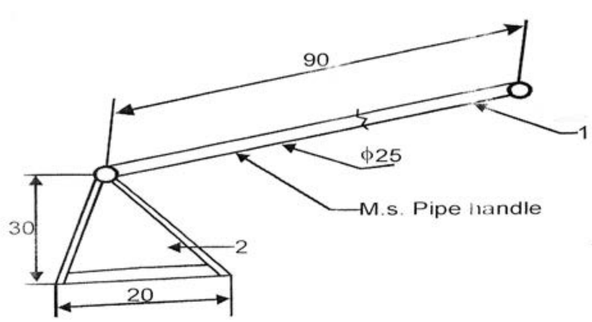


Fig.2 Schematic diagram of short handle hoe

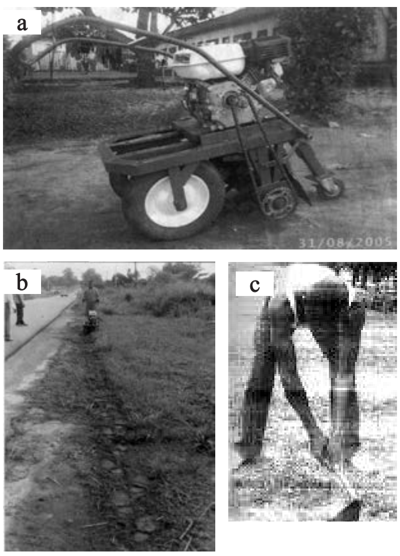


oped a manually operated weeder, which has field capacity greater than the traditional hoe, but weeding performance was limited to a small plot of land in which crops were planted in rows. It was reported that the machine had a low output of about 0.02 ha/hr. This implied that there were many limitation and lower productivity.

Rangasamy *et al*. (1993) evaluated power weeder performance compared to the performance of the conventional method of manual weeding with hand hoe. The field capacity of the weeder was 0.04 ha/hr with weeding efficiency of 95 % for removing shallow rooted weeds. The performance index of the weeder was 453. The cost with the power weeder was Rs. 250 compared to Rs. 490 with dryland weeders and Rs. 720 with manual weeding with hand hoe.

Thus, the objectives of this research were evaluation of the locally designed and fabricated engine powered roto–weeder and its field performance effectiveness in the tropics compared to the short handle hoe.

Field performance
a).Roto weeder, b). Field performance test of the Roto weeder, c). Field performance test of Manual hoe



Materials and Methods

Description of the Weeder: The locally fabricated manually operated petrol engine powered weeder for this research consisted of the following components parts: frame, rotary blade, shaft, ground wheel, sprocket and chain, chassis, cutting depth adjuster, wooden engine mounting, engine and handle.

Fig. 1 is the drawing of the weeder while plate 1 is the photograph of the weeder.

Frame: The frame was made of angle steel welded and bolted together. The frame was the part onto which every other part was fastened and was built to withstand the working operations.

Rotary Blade: The rotary blade was made of mild steel to withstand the wearing condition during its contact with the soil and other foreign material. The rotary blade had a L-shape that made it possible to elb out the top soil with the weeds. The blade was sharpened at an angle of 450 on one side of the blade which made its soil cut very easily.

The Shaft: The bulk of the workload was done with the shaft. It was made of circular steel rod that was held at both ends with rolling bearings. The shaft experienced torque motion and other stresses during operation. The sprocket is fitted to the shaft at one end with a key lock.

Ground wheel: The machine was driven by two ground wheels and a rear roller which made its mobility possible during operation.

The Sprocket and Chain: The machine was operated with two sprockets; one small and one large. The sprockets help to transfer torque motion of the internal combustion engine to the rotary shaft through a chain transmission which was connected from the small sprocket fitted to the internal combustion engine to the larger sprocket of the rotary shaft.

The Chassis: This helped to protect the weeded substance from spraying all over the machine and the operator during operation. It was made of steel flat plate or plastic material.

The Cutting Depth Adjuster: This consisted of square pipe and worked with the principle of a screw jack making it possible to increase the length. The roller was fitted to the adjuster.

Wooden Engine Mounting: This was constructed from a wooden board, and served as an absorber to vibration which could cause crack to the frame and make excessive noise.

The Engine: The machine was powered by a small light weight, minimum horse power internal combustion engine of 1.4 hp, rotating at 1,103 rpm.

The Handle: A handle is made of cylindrical pipe and shaped to the comfort of the operator was attached to the main frame of the machine and could be adjusted as to suit the ergonomic working height of the operator.

Field Tests: The locally fabricated engine powered weeder by Efenudu (2005) was tested in the field and compared with the hand–hoe. Performance was identified in terms of weeding field capacity (ha/hr), weeding efficiency, operational cost N/ha, performance index and fuel consumption (l/hr).

Field Conditions: The field test was conducted at the farm of Rivers State University of Science and Technology, Port Harcourt. During the time of testing the location had well drained soil classified as sandy loam with composition of 76.0 % sand, 7.28 % silt and 15.95 % clay. The moisture content was about 18.0 %. There were three major species of weeds available namely: ipomea spp, trichosma zeyicum and sida alba.

Test Procedures: The tests were made with the locally fabricated roto–weeder with a 1.4 hp petrol engine, stopwatch, measuring rules, short handle hoe, and experimental field of 4.0 m × 2.5 m.

The experimental field was marked in rows, in which the weeding operation was demonstrated. The initial and final time of operation was recorded, along with the productive time.

The effective weeding width of the rotaly cutters and hoe was measured. The theoretical width was the designed width of the weeder. The number of weeds was randomly counted before and after the weeding operations. The depth of cut was also randomly measured, and the average forward speed was obtained. The following calculations were made:

The forward speed of operation was calculated by the equation.

$S = L/t, (m/s)$ .... (1)

where,

S = orward speed (m/s)

L = measured distance (m)

t = recorded time (s)

Theoretical field capacity (Fc_t) was calculated from the rate of field coverage that would be obtained if the weeder were performing its function 100 % of the time at the rated forward speed and always covered 100 % of its rated width.

$Fc_t = S \times Wt$ (ha/hr) .... (2)

where,

Fc_t = theoretical field capacity (ha/hr)

S = forward speed (m/s)

Wt = working width (m)

Field capacity (Fc) was the ratio of the actual area covered in operation to the total time used.

Fc = Area covered / Time used (s) (m^2) .... (3)

Effective field capacity (Fce) was the average output per hour calculated from the total area weeded in hectares and the total work time.

$Fce = Fe \times Fct / 100$ (ha/hr) .... (4)

where,

Fce = effective field capacity (ha/hr)

Fe = field efficiency (%)

Total work time was the time taken from the commencement of the weeding to the end of the weeding operation. It included time taken for turnings at the head fields, rest and any breakdowns or adjustments.

Theoretical time (T_t) was the time that would be required at the theoretical field capacity.

$T_t = 1/Fc_t$ (hr/ha)....................... (5)

Effective operation time (Te) was the time during which the weeder is actually performed its intended function.

$Te = 100T_t / K$ (hr/ha)............... (6)

Table 1 Designed specification of the weeders

Item	Rotor-Weeder	Manual Short-handle hoe
Overall length, (mm)	990	120
Overall width, (mm)	500	20
Overall height, (mm)	760	-
Length of handle, (mm)	1,000	90
Width of cut, (mm)	380	10
Overall weight, (kg)	40	1.5
Maximum depth of cut (mm)	50	20

Table 2 Field test data for the roto-weeder

Row No.	Time taken to weed one row (seconds)	Average speed per row (m/sec)	Turning time (seconds)
1	105	0.038	4
2	109	0.036	6
3	102	0.039	5
4	106	0.037	6
5	108	0.037	8
6	131	0.030	6
Average	11.16	0.036	5.8

Table 3 Field test data for short handle hoe

Row No.	Time taken to weed one row (seconds)	Average speed per row (m/sec)	Turning time (seconds)
1	415	0.0096	2
2	420	0.0095	2.5
3	411	0.0097	2
4	419	0.0095	1.8
5	414	0.0096	2.1
6	422	0.0094	1.5
Average	416.83	0.00955	1.98

Table 4 Effects of weeders on field and weeding parameters

parameters	Weeders	
Iterms	Roto weeder	Short handle weeder
Forward speed (m/s)	0.0032	0.000023
Theoretical field capacity (ha/hr)	0.47	0.0023
Effective field capacity (ha/hr)	0.34	0.012
Theoretical time hr/hr	2.13	437.78
Effective operation time (te)	2.24	515.03
Field efficiency (%)	72	37
Weeding efficiency %	71	70
Performance index	1,700	124
Fuel consumption e/hr	3.2	-
Weeding index	70.4	72
Operating Cost	2,000	8,000

where K is % of implement width actually utilized.

$K = We / Wt \times 100$ (%) ....(7)

where,

We = effective width, (m)

Wt = work width, (m)

Field efficiency (Fe) was the ratio of the actual or effective field capacity (Fce) to theoretical field capacity (Fct). It gave an indication of the loss in the field and failure to use the full working width of the implement.

$Fe (\%) = Fce / Fct \times 100$ .... (8)

or

$Fe (\%) = 100\, T_t / (Te + \sum T_{Loss})$. (9)

where,

T_t = theoretical time (s)

Te = effective time (s)

T_{Loss} = Loss time (s)

Weeding efficiency % was obtained from equation 10

$Weeding\ efficiency\ (\%) = (W_1 - W_2) / W_1 \times 100$ .... (10)

Where,

W_1 = number of weeds before weeding, (no./m^2)

W_2 = number of weeds after weeding, (no./m^2)

Weeding index was a ratio between the number of weeds removed after weeding and the number left in a unit area after the weeding and is expressed as a percentage. The spots where such counts were taken were randomly selected for sampling. This was obtained from **Eqn. 11**.

$Weeding\ index = (W_1 - W_2) / W_1 \times 100$ ....(11)

where,

W_1 = no. of weeds removed after the weeding.

W_2 = no. of weeds left after the weeding.

Performance index indicated how well the machinery was adapted to a specific field, and was the ratio of the products of effective field capacity (Fce) and weeding efficiency to power input of the machine, expressed in as a percentage. It was obtained from **Eqn. 12**.

$Performance\ index = (Fce \times Weeding\ efficiency) / Power\ input \times 100$ .... (12)

The equations stated above were also applicable for determination of those parameters with respect of short handle hoe implement.

Fuel Consumption: The fuel tank of the weeder was initially filled with 3.5 liters of petrol before weeding operation started. And was refilled with 0.6 liters of fuel at the end of the operation. The refilled quantity of fuel represented the quantity of fuel used. Therefore, the fuel consumption is.

$Fc = Fr / t$ .... (13)

where,

Fc = fuel consumption (l/hr)

Fr = refilled quantity of fuel (l)

t = total time of weeding (hr)

Results and Discussions

Field tests were conducted on a well drained soil of sandy loam with composition of 76 % sand, 7.28 % silt and 15.95 % clay. The average time for weeding with the roto-weeder was 11.16 in **Table 2**. The average speed was 0.036 m/s and the turning time was 5.8 s. The field test data for short handle hoe in **Table 3** showed the average time taken to weed as 416.83 s, average speed as 0.00955 m/s and turning time as 1.98 s.

From **Table 4**, the forward speed of engine powered roto-weeder was 0.0032 m/s, theoretical field capacity was 0.47 ha/hr, effective field capacity was 0.34 ha/hr, theoretical time was 2.13 hr/ha, effective operating time was 2.24 hr/ha, field efficiency was 72 %, weeding efficiency was 71 %, performance index was 1,700, fuel consumption was 3.2 l/hr and weeding index was 70.4. The forward speed by the user for short-handle hoe was 0.000023 m/s, theoretical field capacity was 0.0023 ha/hr, effective field capacity was 0.012 ha/hr, theoretical time was 437.78 hr/ha, effective operating time was 515.09 hr/ha, field efficiency was 37 %, weeding efficiency was 70 %, performance index was 124 and weeding index was 72. The operating cost of roto-weeder was N 2,000.00 and N 8,000.00 for manual short-handle hoe.

The engine powered roto-weeder performance was compared with that of the short-handled hoe and the results were shown in **Figs. 3-5**. The results in **Fig. 3** indicated that the field capacity of the roto-weeder was more than that of the manual shor–handle hoe. In **Fig. 4**, it was indicated that the manual short-han-

Fig.3 Field capacity (ha/hr)

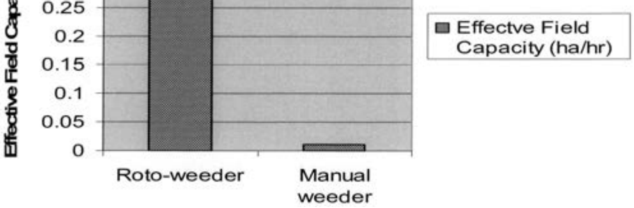
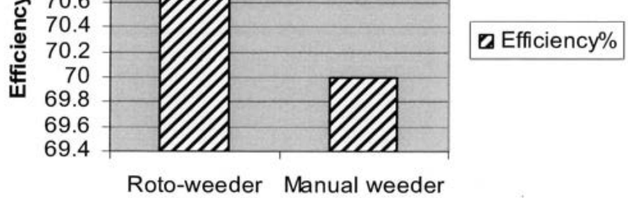


Fig.4 Weeding Efficiency %



dle hoe weeding efficiency was a bit better than the roto-weeder but was time consuming. **Fig. 5** indicates the cost of operation in using the roto-weeder was less as compared to that of manual short-handle hoe.

Based on the results obtained from the field tests, the developed roto- weeder was preferred to the manual hoe.

Conclusion

The engine powered roto–weeder, from it field tests, provided a practical means for mechanical weeding with accuracy, simplicity and speed with considerably lower labour requirement. The developed weeder performed at a depth and width of operation of 3 mm and 350 mm.

The effective field capacity was 0.34 ha/hr, which was about six times that of the manual weeder. The theoretical field capacity was 0.47 ha/hr, more than twenty times that of short-handle manual weeding capacity. It was clear that mechanizing the roto - weeder could lead to replacement of the traditional hoes and cutlasses which dominate small and medium scale farms in the tropics.

The weeder has an ergnomic advantage for the operator as farmers maintain standing position during operation. The roto-weeder would be viable for medium scale farmers. The cost of the weeder is about N 35,000.00 (Thirty–Five Thousand Naira) only.

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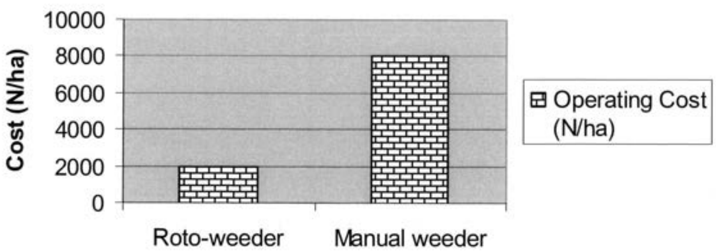
Fig.5 Operational cost (N/ha)



Stage Number Effect on Vertical Line Shaft Deep Well Irrigation Pumps*

by

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Abstract

The effect of stage number on operational characteristics of three different diameter deep well irrigation pumps was researched. The pumps were tested at three different RPM. The characteristics of all stages (1-6) of the pumps were determined in the opt. RPM. The tests were performed according to ISO 2548 regulations in three repetitions.

Statistical analysis was applied on the function of the stage number, power and pressure in fully closed valve (FCV) and flow and best efficiency in full opened valve (FOV).

According to the results of the research, on condition that the shaft diameter and impeller dimension were stable, the effect of stage number variation on power, pressure and efficiency was significant, whereas on flow it was non-significant.

Introduction

Aridity threatens lives and this makes the efficiency of pumps in irrigation plants important in terms of reservoir and energy. Nearly 30 % of the 28 billion hectares of agricultural land can be irrigated economically. According to 2006 data, only 50 % of the mentioned area was irrigated. Based on data from the same year, 65 % of the potential water (total 112 billion cubic meters with 12 billion being subterranean) was used.

It has been reported that 75 % of the consumed water is being used in agricultural irrigation. Referencing these data, it can be said that approximately 12.850 cubic m/hectare year (1.285 mm/year) irrigation water is used for agricultural irrigation. Approximately 10 % of the irrigated fields underwent pressure irrigation (*Kara*, 2005; *Dumlu et al.*, 2006; *Anonymous*, 2007a; *Anonymous*, 2007b). Pressure irrigation systems (irrigation pumping plants) are needed to increase the efficiency and usage of irrigation water. The biggest restrictive factor in the extension of the pressured system is the high cost of the required energy.

Deep well pumps were designed for water supply from subterranean water sources in the areas where there are no above ground water sources or where water transmission is very expensive. The pressure need of the deep well pumps increase as the level of underground water is decreased and the pumping technologies developed. The pressure of the pumps is supplied by increasing RPM and impeller diameter. Some factors, such as motor technology, pump impeller size and mechanical features of the material, restrict the enhancement of the RPM and well diameter restricts the impeller diameter. Therefore, another method for increasing pressure is to use multi-stage (series) pumps. Shaft diameter and hub diameter of the impeller of the deep well pump determine the maximum stage number. The diameter is a function of shaft power and mechanical resistance of the material and shaft power is the function of momentum and RPM. Except for some theoretical approaches, practical tips and catalogue information, very little scientific information is available on the effects of stage numbers on pump operation characteristics (*Baysal*, 1975; *Shulz*, 1977; *Serven*, 1979; *Anderson*, 1986; *Karassik et al.*, 1986; *Saqib* and *Khan*, 1993; *Stepanoff*, 1993; *Nelik*, 1999; *Anonymous*, 2000; *Hanson*, 2000; *Rishel*, 2002; *Çalışır et al.*, 2004; *Çalışır et al.*, 2005).

In this research, the effects of stage number on vertical line shaft

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* The present article was summarized from Sinan Toprak's Master's thesis bearing the same title, which was completed in 2007 at Selcuk University Graduate School of Natural And Applied Sciences Department of Agricultural Machinery.

deep well shaft diameter, on condition that the body and turbine geometry and RPM are stable, pump efficiency and efficiency components was researched.

Material and Method

Three different diameter vertical shaft deep well pumps (4'', 5'' and 6'') commonly used for agricultural irrigation were used. In 2007, the pump was tested at SU Agriculture Faculty according to ISO 2548 standard in the pump test stand of the agricultural machinery department (Hansen, 1974; Anonymous, 1997; Çalışır, 2007). The environmental temperature at the stand was 9-10 ºC and 45-50 % relative humidity. During the test, clean water with a temperature of 13-14 ºC was used.

First of all each of the pumps was mounted as 6 stages. Considering the advice of the manufacturer, each of the pumps was tested for three different RPM. The highest detected RPM was accepted as optimum RPM. In the optimum RPM, with stable clearance and stable shaft diameter, all stages of the pumps were tested from stage 1 to stage 6. The decrease in the RPM of the pumps was realized by eliminating the sub levels of the pumps. In the test stand, a variable frequency driver (VFD) with a 45 kW (50HP) AC electric motor was used. The RPM was measured with a tachometer. The flow rate was measured with a DN 150 electromagnetic flow meter. Pressure was measured with a manometer. The shaft power was measured with a dynamometer. Measurements were made in three replications in the 11 different valve openings, running at least 10 minutes in each opening.

The test results were evaluated as the function of the stage number for each pump separately. A variance analysis was applied to maximum efficiency (%), pressure (bar) and power (kW) for fully closed valve and flow rate at fully opened valve (l/s). LSD test was applied to the parameters that were found significant in the variance analysis. Also, for the three pumps, graphics of the relationships between stage number with efficiency and components of the efficiency were drawn and regression equations and correlation coefficients were identified for the linear model (Anonymous, 1980; Anonymous, 1991).

Results and Discussion

Table 1 identifies, for each pump diameter and stage number, the results of the variance analysis for pressure (bar) and shaft power (kW) at full closed valve obtained with optimum RPM, flow rate (Q) with full open valve and maximum efficiency (η in %) and the LSD. The stage number, pressure, power and efficiency increased as the stage number increased for all three deep well pumps. These increases were statistically meaningful ($p < 0.01$). Stage number was not effective on pump flow rate ($p > 0.05$). The diameter and flow rate of the pumps were proportional. According to average specific speed values, it can be said that these three pumps are mixed flow types. The reason for this increase can be attributed to the decrease of the RPM against increasing flow rate.

With the fully closed valve, the differences between power for the 1st stage and the power per stage up to the 6th stage were significant. The power per stage of the high stage number was smaller than power of the 1st stage. These decrease rates for (4'', 5'', 6'') pumps were calculated successively; 35.05 %, 32.75

Table 1 Effect of the stage number on the efficiency and components of the efficiency of deep well pumps

Pump diameter; Opt. rpm and Ns average specific speed number	Stage number (i) (unit)	Power (at the full closed valve) (P) (kW)	Pressure (at the full closed valve) (p) (bar)	Flow rate (at the full opened valve) (Q) (l/s)	Best efficiency (η) (%)
4'' Opt.rpm 3,050 1/min Aver. Ns 277 1/min	1	2.48^{f}	1.4^{f}	28.37	49.78^{c}
	2	4.20^{e}	2.8^{e}	27.43	57.50^{ab}
	3	5.81^{d}	4.2^{d}	28.37	55.03^{b}
	4	7.65^{c}	5.6^{c}	27.32	56.90^{ab}
	5	9.48^{b}	7.0^{b}	25.38	58.47^{a}
	6	11.08^{a}	8.4^{a}	27.26	59.47^{a}
	LSD (% 1)	0.4732	0.2087	-	2.597
5'' Opt.rpm 2,400 1/min Aver. Ns 253 1/min	1	3.81^{f}	1.6^{f}	43.61	60.67^{d}
	2	6.86^{e}	3.2^{e}	43.60	62.87^{cd}
	3	9.79^{d}	4.6^{d}	43.27	63.57^{bc}
	4	13.29^{c}	6.0^{c}	43.28	64.33^{bc}
	5	16.09^{b}	7.6^{b}	43.29	65.43^{ab}
	6	17.19^{a}	9.2^{a}	42.86	66.93^{a}
	LSD (% 1)	0.4925	0.2231	-	2.228
6'' Opt.rpm 1,600 1/min Aver. Ns 237 1/min	1	2.39^{f}	1.0^{f}	51.72	53.57^{c}
	2	3.90^{e}	2.0^{e}	51.87	61.90^{ab}
	3	6.08^{d}	3.1^{d}	51.09	60.63^{b}
	4	7.73^{c}	4.2^{c}	51.08	62.78^{ab}
	5	9.63^{b}	5.2^{b}	51.51	64.67^{a}
	6	11.54^{a}	6.2^{a}	51.42	63.50^{ab}
	LSD (% 1)	0.7185	0.2087	-	2.597

% and 24.48 %.

At each of the pumps, the pressure obtained at closed valve increased significantly depending on the stage number. However, for each of the three pumps there was no significant change among the pressure per stage produced from the 1st stage to the 6th stage.

For all stage numbers (1...6) of each of the pumps had the same flow rate.

As stage number increased, the maximum pump efficiency obtained at optimum stage numbers increased. The increased rates between efficiency of the 1st stage with efficiency of the 6th stage were 19.47 %, 10.32 % and 18.54 % for 4", 5" and 6" pumps, respectively.

Figs. 1-4 graphically present the operational characteristics as a function of the stage numbers at the opt. RPM of the pumps.

For the fully closed valve, the regression equation and determination coefficient of the pressure change with stage number were identified as

$y = 1.4 \times (R^2 = 1);$

$y = 0.1067 + 1.5029 \times (R^2 = 0.9993)$ *and*

$y = -0.0533 + 1.0486 \times (R^2 = 0.9996)$

for 4", 5" and 6" pumps, respectively, for the linear models. The relationship between stage number and pressure was found significant (**Fig. 1**).

For the fully closed valve, the regression equation and determination coefficient of the power change with stage number were identified as

$y = 0.6887 + 1.7505 \times (R^2 = 0.9986);$

$y = 1.3641 + 2.8025 \times (R^2 = 0.9846)$ *and*

$y = 0.4175 + 1.8457 \times (R^2 = 0.9986)$

for 4'', 5'' and 6'' pumps, respectively, for the linear model. The relationship between stage number and shaft power were significant for all three stages. The shaft power needs of the 4 and 6 pumps were measured equal. This can be explained with the efficiency power of the shaft power to the flow, pressure and productivity (**Fig. 2**).

For the full opened valve, the regression equation and determination coefficient of the flow change with the stage number were identified as

$y = 28.548 - 0.3688 \times (R^2 = 0.4671);$

$y = 45.116 - 0.4186 \times (R^2 = 0.6301)$ *and*

$y = 49.907 + 0.2981 \times (R^2 = 0.7412)$

for 4", 5" and 6" pumps, respectively, for the linear model. The relationship between stage number and flow for all pumps was non-significant. At increased stage numbers, pump flow remained relatively constant. (**Fig. 3**)

The regression equation and determination coefficient for the best efficiency change as a functions of stage number were identified as

$y = 0.5058 + 0.0153 \times (R^2 = 0.7264);$

$y = 0.5734 + 0.0106 \times (R^2 = 0.9711)$ and

$y = 0.5469 + 0.0174 \times (R^2 = 0.6743)$

for 4'', 5'' and 6'' pumps, respectively for the linear model. The relationship between stage numbers and efficiency was be significant. However, it can be said that the relation for pump number 6 was weak. The reason was that the increase in the pressure was lower than the power increase. The most significant relationship was observed in pump 5. (**Fig. 4**).

Conclusion

The following conclusions were drawn with respect to the tested vertical shaft deep well pumps that were multistage (or serial mounted) when the shaft diameter, impeller dimension and RPM were stable;

- As the stage number increased, the pump shaft power increased proportionally. (R^2 = 0.9846…0.9986). However, depending on the increasing stage number, the power consumption per each stage decreased at the rates of 24.5 %…35.1 %.
- As the stage number increased for all pumps, pump output pressure had a linear increase (R^2 = 0.9996…1) but the pressures per one stage were stable.
- The flow rate was unaffected by stage number (R^2 = 0.4671…0.7412).
- For each of the pumps, maximum pump efficiency values increased

Fig. 1 The effect of stage number on pressure for the multistage deep well pumps

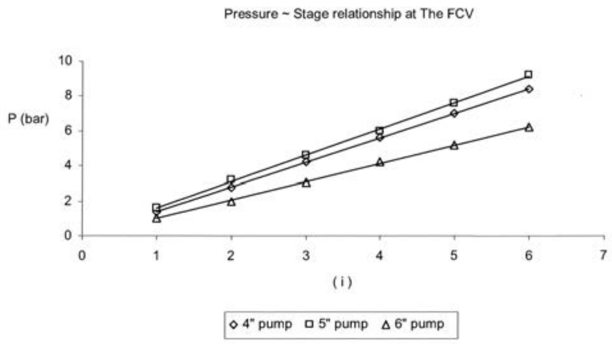
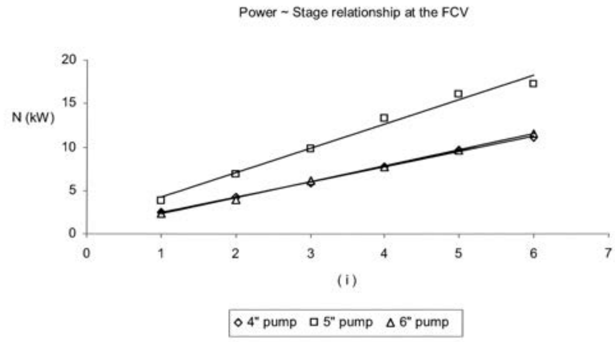


Fig. 2 The effect of stage number on power for the multistage deep well pumps



depending on the stage number (R^2 = 0.6743…0.9711). Increased rates of the efficiencies were 10, 32 % -19 and 50 %.

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Fig. 3 The effect of stage number on the flow of the multistage deep well pumps

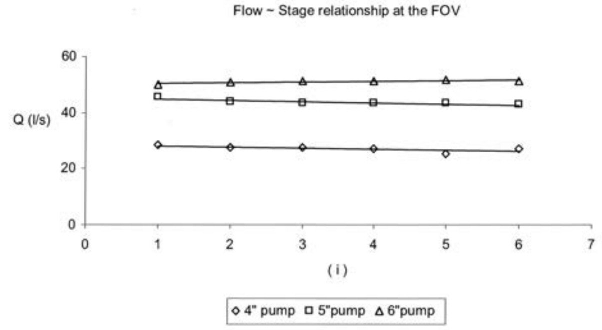
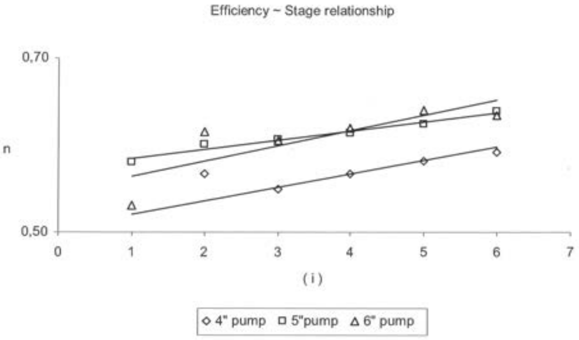


Fig. 4 The effect of stage number on efficiency for the multistage deep well pumps



Effect of Pure Biodiesel on Fuel Injection Systems and Noise Level in Agricultural Diesel Engines

by

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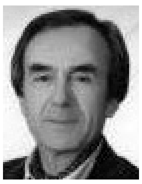

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Abstract

Petroleum fuels have caused environmental problems that affect the whole atmosphere and some estimate the depletion of petroleum in 50-100 years. Mankind has turned their attention toward alternative, renewable energy sources to meet energy requirements. Biodiesel (refined) of canola and a new FIAT 60-56 tractor engine were principal items of this research. Experiments included a total of 100 hours while the engine speed was fixed at 1,500 rpm. The effects of biodiesel were observed on fuel injection pump, injectors, filters and fuel tank at the end of 100 hours engine run. Neat biodiesel has caused residuals to clog fuel filters, decay of rubber lines and dark zone, sticking on parts of injection system, injector choking, filter plugging, and severe engine lubricant degradation. Therefore, neat biodiesel (B100) can not be used in current diesel engines in the market. Noise level with the biodiesel was lower than the noise level of the diesel and a better exhaust smell was noticed with biodiesel fuels than diesel fuel.

Introduction

Biodiesel (fuels) are methyl or ethyl esters derived from a broad variety of renewable sources such as vegetable oil, animal fat and cooking oil. Esters are oxygenated organic compounds that can be used in compression ignition engines because some of their key properties are comparable to those of diesel fuel. Biodiesel is produced in a pure form (100 % biodiesel fuel referred to as "B100" or "neat biodiesel") and may be blended with petroleum-based diesel fuel. Such biodiesel blends are designated as BXX, where XX represents the percentage of pure biodiesel contained in the blend (*Anonymous*, 2003).

Vegetable oil is easily available worldwide. It is a renewable fuel with short carbon cycle period (1-2 years compared to millions of year for petroleum fuels) and is environmentally friendly. These are the triggering factors for research all over the world to consider vegetable oils and their derivatives as alternative to petroleum diesel. However, a major disadvantage of vegetable oil is its viscosity, which is an order of magnitude higher than that of mineral diesel. The fuel injection system of new technology engines is sensitive to fuel viscosity changes. High viscosity of vegetable oil leads to poor fuel atomization, which, in turn, may lead to poor combustion, ring sticking, injector cocking, injector deposits, injector pump failure and lubricating oil dilution by crank-case polymerization (*Agarwal* and *Das*, 2001; *Agarwal et al*., 2003; *Agarwal* and *Rajamanoharan*, 2009).

The aim of this paper was to determine the possibility of using pure biodiesel (B100) on a fuel injection system for a diesel engine. In addition to those, it was purposed to give an idea for further researchers that will study biodiesel.

Experimental Setup and Procedures

Relevant properties of the test fuel used in the research are given in **Table 1**. The specifications of the direct injection diesel engine are shown in **Table 2**.

There is a CAV made injection pump and injector coupled with the engine. Filters were made by Lucas Company. The CAV transfer pump is the positive type. It has two vanes sliding inside an eccentric liner in the hydraulic head. The transfer pump rotor is carried in the end of the distributor rotor. The capacity of the transfer pump is considerably in excess of injection pump requirements. The injection pump was previously tested with diesel fuel before starting the experimental process. The results obtained are shown in **Table 3**. The injection pump was finally tested after the running period with biodiesel. Levels of wear in elements of the pump were determined and compared to their original values. **Table 4** indicates technical features of the pump.

The experimental engine was operated at a constant 1,500 rpm throughout the wear period for pure biodiesel. The engine was operated 100 h for each test of biodiesel. The engine was operated a total of 300 hours (*Kalam* and *Masjuki*, 2002).

Components were investigated at the end of every 100 hours of operation by disassembling the parts of injection system. There was wear on the injection pump, injectors, filters, valves and fuel tank. In addition, the amount of soot that is on elements of the fuel system was weighted with an electronic balance (Mark of PRECISA and model of XB220A, with accuracy of 0.0001 g).

Pressures of injectors and injector pump were measured while running with diesel fuel. Injection pressure was measured each 100 hours running intervals with biodiesel. Data were compared with previous original values for quantity of wear. The filter was replaced every 100 hours. The fuel tank was cleaned and sediment weighted before acidity grade was determined.

A simulated driver seat was set referencing to the tractor of the Fiat 60-56 model in order to measure noise level (**Fig. 1**). Noise levels of the engine were determined at the 1,500 rpm. A digital sound level meter, SL 4001, was used. Noise level was measured in dB with A-weighting, expressed as dB (A). The microphone was located 250 mm to the side of the central plane of the seat, the side being that on which the higher noise level was encountered (*Anonymous*, 1977).

Table 4 Technical features of injector

Nozzle type	Hole
Number of orifice	3
Injection pressure (Bar)	265
Orifice diameter (mm)	0.35

Table 1 Characteristics of the biodiesel

Fuels	Result	Specification DIN EN 14214	
		Min	Max
Density at 15 ºC(kg/m^3)	888	860	900
Specific combustion enthalpy (MJ/kg)	39.80		
Cetane number	51.3	51	-
Iodine number	129.7	-	130
Kinetic viscosity (40 ºC mm^2/s)	4.4	3,5	5.0
Sulfur content (mg/kg)	≤ 1 ppm	-	10
Percentage of humidity (%)	0.13		
Acid value (mg KOH/g)	0.336	-	0.5
Diglyceride content % (m/m)	≤ 0.2	-	0.2
Triglyceride content % (m/m)	≤ 0.2		0.2
Monoglyceride content % (m/m)	≤ 0.8	-	0.8
Total Glycerol % (m/m)	≤ 0.25	-	0.25

Table 2 Technical properties of the diesel engine

Engine	FIAT
Model	60-56
Type	Water-cooled, four stroke
Combustion	Direct injection (DI) and naturally aspirated
Number of cylinders	3
Bore and stroke	104 × 115 mm
Displacement	2,931 cm^3
Compression ratio	17:1
Nominal rated power	44 kW
Maximum torque speed	1,500 rpm
Combustion chamber	Swirl chamber

Table 3 Technical characteristics of injector pump

Process	Rpm	
	750	1,420
Transfer pump pressure (Bar)	3.5	-
Average amount of fuel (cm^3/ 200 stroke)	11	2
Difference between amount of fuel comes from injectors (cm^3/ 200 stroke)	< 1	-

Table 5 Test results regarding injector pump

Process	Rpm	
	750	1,420
Transfer pump pressure (Bar)	3.5	-
Average amount of fuel (cm^3/ 200 stroke)	11	2
Difference between amount of fuel comes from injectors (cm^3/ 200 stroke)	< 1	-

Result and Discussion

Injection Pump

There were black-dense zones on the injection pump elements and the seal became soft. The engine failed after 70 hours running time in the first experiment, 80 hours in the second and 80 hours in the third experiment. The problem was in the injection system because adhering was observed on plungers of the injection pump. Experiments were continued after pump plungers were cleaned by removing the gum. **Table 5** shows test results for 100 hours running interval of the injection pump. There were no significant differences running with biodiesel or diesel fuel. There was not any considerable wear on the elements of the pump injection system.

Injectors

Dark zones on injector pin and nozzle, and the over softened seal was observed (**Fig. 2**) to be a possible problem. Excessive toughening occurred on backward plastic pipes. Besides that, problems with injection performance arose because of extreme C accumulates. The experimental process continued after injectors were cleaned.

High viscosity of vegetable oil leads to poor fuel atomization, which, in turn, may lead to poor combustion, ring sticking, injector cocking, injector deposits, injector pump failure and lubricating oil dilution by crank-case polymerization (Agarwal and Das, 2001; Agarwal *et al*., 2003; Agarwal and Rajamanoharan, 2009). The injector nozzles that operated on neat rapeseed oil were more coated by carbonaceous deposits than injector nozzles that operated on the mineral diesel. Control studies of valve lifting opening pressure and visual evaluation of fuel sprays confirmed that all injectors were still within the norm, suitable for further operation (Pehan, *et al*., 2008).

Filters

Dark fields were observed on the fuel filter. Since cloggages often occurred, fuel filters need to be changed as rapid as necessary. **Fig. 3** shows an original fuel filter, one used for biodiesel and one used for mineral diesel. Neat biodiesel can solidify in fuel lines or clog filters when utilised in cold ambient conditions (Smith *et al*., 2009).

Fuel Tank

Sediment accumulated in the bottom of the fuel tank at the end of each 100 hours running time. Precipitate, unlike biodiesel characteristics, were observed by gas

Fig. 1 Prepared system for determining noise level of the engine

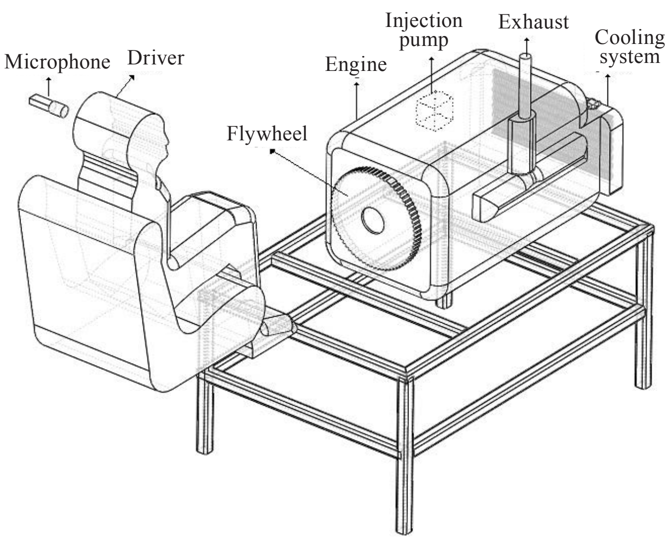


Fig. 2 Seal deformation and C residue of the injector

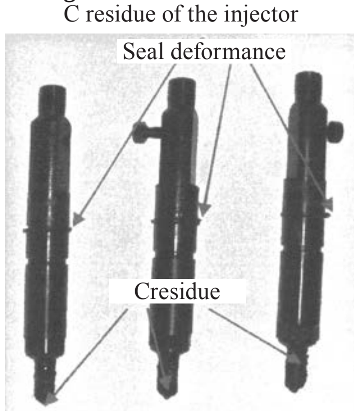


Fig. 3 Comparison of filters

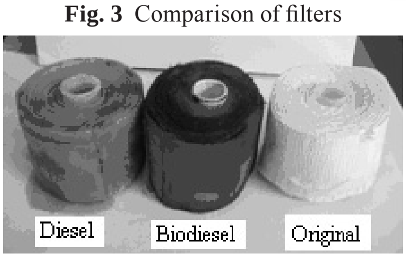
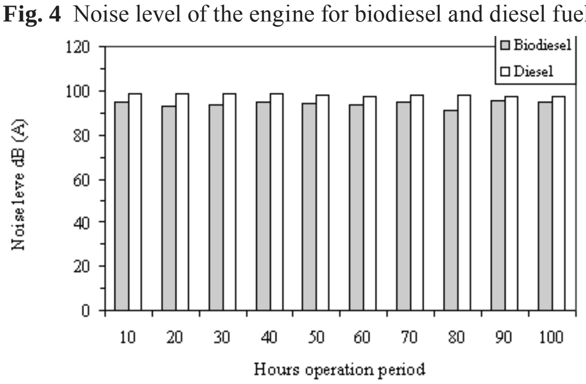


Fig. 4 Noise level of the engine for biodiesel and diesel fuel



chromatograph analyzer. Acidity of precipitate was 15 ffa (free faty acids).

Neat biodiesel caused a variety of injection system problems, including dark zone and sticking on parts of the injection system, injector coking, filter plugging, decay of rubber lines and gaskets and severe engine lubricant degradation. Bona *et al*. (1999) pointed out that a pure form biodiesel may give rise to several negative effects on diesel engine functioning.

Noise Level

Results of noise level for the engine while running both biodiesel and diesel can be seen in **Fig. 4**. The average of the lowest noise level, 88.2 dB (A), was measured in a period of 80 hours for biodiesel. An average of maximum noise levels, 101.9 dB (A), were measured after a 50 hour duration for diesel. Noise level was spread out over the range of 88.2 dB (A) to 96.9 dB (A) for biodiesel and 100.4 dB (A) to 101.9 dB (A) for diesel. Noise level of the biodiesel was lower than the noise level of the diesel. Less noise and a better exhaust smell was noticed with biodiesel fuels than diesel fuel. Purcella (2006) pointed out that biodiesel reduced the classic diesel engine "knocking" noise.

Conclusion

Neat biodiesel has handicapped diesel engines causing residuals to clog the fuel filters and decay rubber lines and dark zone and stick on parts of the injection system, injector coking, filter plugging, and severe engine lubricant degradation. Therefore, neat biodiesel (B100) can not be used in current diesel engines in the market. It might be an alternative fuel to diesel if some improvements could be achieved on the fuel system. Noise level of the biodiesel was lower than the noise level of the diesel along with a better exhaust smell.

Recommendations for Using Biodiesel:

1. Construction of a new fuel system better suited to biodiesel characteristics,
2. Regular cleaning of the fuel tank,
3. Frequent changing of fuel filters,
4. Make filters of suitable materials for biodiesel,
5. Developed suitable engine oils for biodiesel.

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Economic Evaluation of Investment in Animal Traction a Case Study of Katsina State, Nigeria

by

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Abstract

This study was designed to assess the profitability or otherwise of investing in animal traction technology adopted by small scale farmers in Katsina State, Nigeria. This was achieved through the estimation of the various rates of return to the investment. Sensitivity analysis was also conducted to test the effects of varying the costs and returns on the rates of return to the investment on the technology. Data used for the study came from a field survey conducted in three local government areas of the state. A structured questionnaire was designed and distributed to ninety (90) animal traction farmers using only one pair of workbull. The analytical tool employed was the cost and return analysis using the rates of return model of investment analysis. Specifically, the net present value (NPV), internal rate of return (IRR) and payback period (PBP) were adopted. The rates of return to the investment established an NPV of N149, 343.00, an IRR of 71 % and the value for the PBP of 2 years, thus, indicating that the investment was highly profitable. These rates remain profitable even if revenue is decreased by 10 % or investment cost increased by the same percentage. The results also showed that the investment was more sensitive to a decrease in output or revenue producing a greater magnitude of decreases in NPV of 16 % compared to a decrease in NPV of 6 % when investment cost was increased by the same proportion.

Introduction

The development of smallholder agriculture has received attention from government and development planners in Nigeria, and in many African countries. In Nigeria, small-scale farmers constitute about 90 % of the farming households and have been the major producers of food and agricultural raw materials (*Abalu,* 1986 and *Adesimi*, 1991). Although medium and large-scale farmers are gradually emerging, Nigeria will continue to depend largely on smallholder agriculture for its food supply and economic stability for many years to come.

Animal traction (AT) or animal draft is the use of animals. mainly bullocks, for a wide range of purposes in agriculture. This includes utilization in ridging, weeding and transportation of farm produce from the farm and organic manure to the farm.

The power needs in agriculture have grown rapidly in the past twenty years. More power, timely power and greater speed are required to cope with the opportunities for increased food and cash crop production offered by high yielding varieties, fertilizer and modern farming technology (Hopfen, 1968). This has led to an increase in both engine and animal power in Asia, Latin America and Africa, and to an increase in engine power alone in North America, Europe and Oceania. Animal traction has played and still plays an important role in meeting the power requirements in many parts of developing world because it is recognized as an appropriate, affordable and sustainable technology requiring few external inputs and hence relatively low capital investment cost.

One of the many problems of the agricultural sector is the acute shortage of labour experienced by small-scale farmers especially at the peak of the farming season. This shortage in rural labour supply is largely due to rural urban drift of youths in search of better wages in the expanding high income sector (Oyejide, 1986). The increase in the enrollment of children for primary education has also partly contributed to the squeeze on rural labour supply (Philip et al., 1990). Labour shortage not only limits the scale of production, but also adversely affects yield (Norman, 1973). In order to bring a solution to this problem, the government introduced mechanical power in the form of a tractor hiring scheme and the subsidization of the cost of tractors. However, most of these schemes failed, not just because of the administrative problems, but also because the technology was in appropriate for the small-scale farmers situation (*Fashina*, 1980 and *Pingali et al*., 1987).

It is now an empirical fact that the introduction of a new technology to farmers operating in a particular farming system does not guarantee widespread adoption and efficient use. Experience has shown that success in this respect depends on fulfillment of certain specific economic, technical and institutional conditions. The technology has to be economical, more profitable than existing technology and technically easily manageable by the target group. Finally, the availability of the new technology and all inputs to the farmers at the right time and place and right quantity and should be guaranteed (Hailu, 1990).

The present study was conducted to determine the economic profitability of investment in AT technology as applicable to the small scale farmer's environment and farming system.

Methodology

The study was conducted in Katsina state. The state lies in the Sahel-Sudan agro-ecological zone of Nigeria. The major crops grown are millet, Sorghum, groundnut, cowpea, cotton and maize. Bullocks are the predominant animals used for draft cultivation involving ridging and ploughing. Animal transport is also a common feature of AT in the state. Sampling was restricted to only those farmers using one pair of workbull for crop production. Purposive sampling of three local government areas cutting across the major agro-ecological zones of the state was done. Two villages from each of the three local governments and finally fifteen AT farmers were selected. Thus, a total of 90 AT farmers were used for the study.

Data Collection and Analysis

Primary and secondary data were used for the study using a structured questionnaire and interview schedules. The variables on which data were collected are those related to AT investment variables like sources of capital, work animals and their purchase prices (N/bull), source of AT equipment and accessories and their prices (N/equipment or accessories), the resale prices of animal (N/bull), resale prices of equipments after their assumed life span, and additional income from contract hiring (contract work on other peoples farms).

The data were analyzed using the rates of return model of investment profitability analysis. Returns to the investment were compared with the cost through both the discounted, i.e internal rate of return (IRR), and net present value (NPV) and undiscounted, i.e. payback period (PBP) cash flow measures. Both the NPV and IRR are given by the equation below

$$NPV = \sum_{t=0}^{n} \frac{Bt - Ct}{(1+i)^t}$$

$$IRR = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+i)^t} = 0$$

Where:

Bt = net return for period "t"

Ct = total estimated cost of capital items (pair of draft animal, ridger, cultivator and accessories like yoke, nostril rope and muzzle), and operating costs

n = number of years

t = time period in years (t = 0, 1, 2…n) which is the terminal end of the life of the investment.

i = interest rate or discount rate.

Notes and Assumptions to Facilitate Data Analysis:

1. The cost of animal training, shelter and insurance was excluded as these are not undertaken by the farmers in the study area.
2. Straight-line depreciation schedule was used for estimation
3. The estimated salvage value of equipment and resale price of animals were based on the subjective valuation of the farmers.
4. The cost of the pair of draft animals, the ridger, cultivator, hand tools and other accessories constituted the initial investment requirements for the AT farmers.
5. Each pair of draft animals, accessories and hand tools will be replaced after 3 years; the main traction equipment (ridger and cultivator) will be replaced after 12 years. Cost of equipment repair and maintenance will be on annual basis.
6. The discount factor was the ceiling lending rate for the year of study. Its value was 19 %.
7. It will be assumed that the majority of the farmers have more than three years farming experience using AT and have, therefore, passed the critical learning experience stage of 1 to 3 years and output is stable, leading to constant return to the scale of factors of production used in the projected statement for animal traction in **Table 1**.

NPV is defined as the present worth of the incremental net benefits, incremental cash flow stream, or simply the present worth of income stream generated by an investment. The formal selection criterion for the NPV is to accept all investments with a zero or greater NPV. The IRR is the discount rate that makes the NPV of the incremental net benefit stream or incremental cash flow equal to zero. This discount rate (interest rate) is the interest that a project could pay for the resources used if it is to recover its investment and operating costs and still break even. The formal selection criterion for the IRR is to accept all investments having an IRR equal or greater than the opportunity cost of capital, i.e the interest rate. The two discounted cash flow measures (NPV and IRR) were calculated using the pre-programmed computer spreadsheet software @ NPV and @ IRR, at a discount rate of 19 %, which was the bank lending rate or the real "opportunity cost" of capital in Nigeria the year the study was conducted.

The Payback Period (Pbp) is Given as:

$$PBP = \frac{\text{Initial investment outlay}}{\text{Annual net cash flow}}$$

The initial investment outlay consisted of cost of hand tools, a pair of work bulls AT equipment and accessories and rent on land, while the annual net cash flow consisted of amounts the farmers saved through the use of AT, annual profit from animal fattening, revenue from contract ridging and the average annual residual value of equipment.

Sensitivity analysis was conducted to test the effects of varying economic parameters like cost and return on the profitability of the investment. This determined the impact of the change in costs and return on the attractiveness of the investment with respect to the values of NPV and IRR. The sensitivity analysis involved a 10 % decrease in yield (expressed as revenue) and a 10 % increase in cost. This analysis was done separately for the above economic parameters while holding other parameters constant.

Results and Discussion

The process of assessing the impact of animal traction investment to determine the rates of return involved combining farm level costs and related economic parameters to produce a number of quantitative indicators such as the NPV, IRR and PBP. The results of the analysis of the streams of net annual economic benefits are shown in **Table 1**. This information on **Table 1** was used to compute NPV and IRR.

The result showed an NPV value of N149,343 and IRR of 71 %. These were substantially high and competitive rates, indicating that investment in AT technology was profitable in Katsina state. The IRR was comparable in magnified to those obtained for a similar study conducted by Panin (1988) in Northern Ghana (51 %).

All the conditions of acceptance of a viable investment have been satisfied in this study, (positive NPV and IRR greater than the discount rate) given the magnitude of the NPV (N149,343) and IRR (71 %). The result of the net incremental benefit over the life of the investment was also considered. The total net incremental benefit over the life of investment amounted to N618,178. Not withstanding, the overall positive net incremental benefit of the investment, the farmer faces financial difficulty during the first year of adoption of the AT technology as a result of the high initial investment cost of N97,152 as compared to N1,709.00 for the non-AT farmer (**Table 1**).

The result showed the PBP of 1.8, but since the fractional part of the answer is not very meaningful, you can not be sure of paying for the amount invested until at the end of the second year. Hence the PBP is taken on 2 years.

The result of the sensitivity analysis is presented in **Table 2**. It shows the effects of a 10 % reduction in revenue and a 10 % increase in investment cost on the investment's rate of return, holding all other variables constant. The results showed that when the investment cost was increased by 10 %, the NPV decreases by 6 % (from N149,343 to N140,871) while IRR change from 71 % to 63 % representing 8 % point reduction. In other words, the investment still remains profitable. Holding all other variables constant, the total revenue was reduced by 10 %. The result showed that the effect on the investment worth was still favourable. The NPV decrease by 16 % from N149,343 to N125,937, while IRR decrease by only 7 % points from 71 % to 64 %. The results also showed that the investment is more sensitive to a decrease in output or revenue, producing a greater magnitude of decreases in NPV of 16 % compared to a decrease in NPV of 6 % when investment cost was increased by the same proportion. The result of the sensitivity analysis shows that even if errors had been committed, probably due to data inadequacies by under estimating the investment cost or over estimating the return by about 10 %, the investment still remains profitable.

Conclusion

Investment in AT for farming is a high capital investment within the context of Nigerian economic situation but with very high pay offs. This study has demonstrated that investment in the technology in Katsina state have been very successful. With estimated NPV of N149,343 and IRR of 71 %, these investments have been highly profitable given the bank lending rate of 19 %. Given the Nigerians commitment to efficiency of resource utilization and economic growth in the context of free market economy, the government will need to place more emphasis on profitability as a basic parameter for determining the size and composition of its investment in agriculture.

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Table 1 Projected investment costs and revenues from animal traction in Katsina State (x)

Items of Costs and Returns	Year of Investment						
	Oa	1	2	3	4	5	6
SOURCES of REVENUE							
Crop Sales	181,148.00	181,148.00	181,148.00	181,148.00	181,148.00	181,148.00	181,148.00
Contract Ridging	-	4,678.00	4,678.00	4,678.00	4,678.00	4,678.00	4,678.00
Animal Resale	-	-	-	165,632.00	-	-	165,632.00
AT Equipment Residual Value	-	-	-	-	-	-	-
TOTAL REVENUE	181,148.00	185,826.00	185,826.00	351,458.00	185,826.00	185,826.00	351,458.00
VARIABLES COST							
Seed, Fertilizer + Chemicals	34,564.00	34,564.00	34,564.00	34,564.00	34,564.00	34,564.00	34,564.00
Labour	61,785.00	61,785.00	61,785.00	61,785.00	61,785.00	61,785.00	61,785.00
Power hiring	22,600.00						
Feed + Medication + Tools Repair	-	1,906.00	1,906.00	1,906.00	1,906.00	1,906.00	1,906.00
TOTAL VARIABLE COST	118,949.00	98,255.00	98,255.00	98,255.00	98,255.00	98,255.00	98,255.00
INVESTMENT COST							
Hand Tools	322.00	322.00	-	322.00	-	-	322.00
AT Equipment & Accessories	-	8,616.00	-	455.00	-	-	455.00
Animal Cost	-	86,827.00	-	86,827.00	-	-	86,827.00
Rent on Land	1,387.00	1,387.00	1,387.00	1,387.00	1,387.00	1,387.00	1,387.00
TOTAL INVESTMENT COST	1,709.00	97,152.00	1,387.00	88,991.00	1,387.00	1,387.00	88,991.00
TOTAL EXPENSES	120,658.00	195,407.00	99,642.00	187,246.00	99,642.00	99,642.00	187,246.00
NET BENEFIT	60,490.00	−9,581.00	86,184.00	164,212.00	86,184.00	86,184.00	164,212.00
INCREMENTAL NET BENEFIT	-	−70,071.00	25,694.00	103,722.00	25,694.00	25,694.00	103,722.00

Items of Costs and Returns	Year of Investment					
	7	8	9	10	11	12
SOURCES of REVENUE						
Crop Sales	181,148.00	181,148.00	181,148.00	181,148.00	181,148.00	181,148.00
Contract Ridging	4,678.00	4,678.00	4,678.00	4,678.00	4,678.00	4,678.00
Animal Resale	-	-	165,632.00			165,632.00
AT Equipment Residual Value	-	-	-	-	-	5,899.00
TOTAL REVENUE	185,826.00	185,826.00	351,458.00	185,826.00	185,826.00	357,357.00
VARIABLES COST						
Seed, Fertilizer + Chemicals	34,564.00	34,564.00	34,564.00	34,564.00	34,564.00	34,564.00
Labour	61,785.00	61,785.00	61,785.00	61,785.00	61,785.00	61,785.00
Power hiring						
Feed + Medication + Tools Repair	1,906.00	1,906.00	1,906.00	1,906.00	1,906.00	1,906.00
TOTAL VARIABLE COST	98,255.00	98,255.00	98,255.00	98,255.00	98,255.00	98,255.00
INVESTMENT COST						
Hand Tools	-	-	322.00	-	-	-
AT Equipment & Accessories	-	-	455.00	-	-	-
Animal Cost	-	-	86,827.00	-	-	-
Rent on Land	1,387.00	1,387.00	1,387.00	1,387.00	1,387.00	1,387.00
TOTAL INVESTMENT COST	1,387.00	1,387.00	88,991.00	1,387.00	1,387.00	1,387.00
TOTAL EXPENSES	99,642.00	99,642.00	187,246.00	99,642.00	99,642.00	99,642.00
NET BENEFIT	86,184.00	86,184.00	164,212.00	86,184.00	86,184.00	257,715.00
INCREMENTAL NET BENEFIT	25,694.00	25,694.00	103,722.00	25,694.00	25,694.00	197,225.00

Note Oa = Farmers who did not use animal traction

Source: Study data 2006

Table 2 Effects of a 10 % decrease in total revenue and a 10 % increase in cost of investment

Change in costs and revenue	NPV (N)	Change in NPV	IRR (%)	Change in IRR (%)
** N0 change in costs and revenue	149,343.34	0	70.60	0
10 % increase in costs	140,871.20	6	62.78	8
10 % decrease in revenue	125,936.70	16	63.50	7

** Control

Source: Study data

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Thermal Efficiency Enhancement of a Solar Drier for Hay Making from Sugar Beet Tops

by

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Abstract

Selection of driers for a particular application is largely a decision based on what is available and the types of driers currently used widely. Some very recent developments in solar drying technology are highlighted. An investigation of the possible use of sugar beet by-products was carried out, in order to approach zero-waste from sugar beet tops. This research aimed at proposing and testing an alternative method for producing sugar beet tops hay via hot air drying. A greenhouse solar drier of 1.95 m^2 floor area (east-west orientation) was improved for faster drying using rotary a drum type drier under double layer covered plastic greenhouse with a 4 cm dead air space. The greenhouse solar drier was fabricated, developed and tested for drying sugar beet tops under Egyptian climatic conditions. Drying sugar beet tops in the drier reduced the moisture content from about 88.13 to 10.64 % db in 7 h. The experimental investigations were conducted with a drying airflow of 2.481 to 8.862 m^3/min. The drying rate increased with drying airflow rate, hence reducing the total drying time. In particular, as drying airflow rate was raised from 2.481 to 5.473 m^3/min, the time period needed to reduce the moisture content of the sample from 88.13 to about 12.86 % (dry basis) decreased from 540 to 420 min (− 22.22 %). The average thermal efficiency of the solar drier was estimated to be about 47.53 ± 1.05, 94.67 ± 0.91 and 85.53 ± 1.42% at drying airflow rates of 2.481, 5.473 and 8.862 m^3/min, respectively. The strong influence of drying airflow rate on the thermal efficiency and drying rate at the early stage of drying was evident. Two empirical drying models for describing time dependence of the moisture ratio change were fitted to experimental data and model parameters in equations were determined by using a nonlinear regression. By using of a constant and a coefficient determined in this study, the change of moisture ratio with time could be described by the simple exponential drying model in the airflow range of 2.481-8.862 m^3/min. In this research a new approach for employing solar radiation as the main source of energy for sugar beet tops drying was introduced. Concerning this aspect, the double layer plastic covered greenhouse solar drier with 4 cm dead air space had the maximum air temperature in the drier of 52 ºC compared to other dead air spaces tested in the present study. The proposed solar drier was able to reduce moisture of the tested product to the recommended level (10.64 % db) in the first day. In addition, the development and testing of a new type of efficient solar drier, particularly meant for drying crop residues, was fully described.

Introduction

Due to the lack of fodder crops and concentrates for feeding farm animals, nutritionist thought about the nutritive values of crop by-products and the possibility of using them for feeding animals as they were, or after improving nutritive values either physically, chemically or biologically. One of these crops, which gives a very huge amount of

Acknowledgements

The author is grateful for the support of the staff and facilities of Animal Production Research Laboratories (APRL, Sakha, Kafr El-Sheikh, Egypt). The author also wishes to acknowledge Dr. G. H. A. Ghanem, the head of APRL for technical assistance in preparing **Table 2**. Thanks are also due to the Delta Company of Sugar in Kafr El-Sheikh governorate, Egypt for providing sugar beet tops.

by-products, is sugar beet. Sugar beet is planted in Egypt mainly for sugar production and the tops of the plants are not used for any other purpose. However, this by-product is not safe to be used as such, and feeding considerable amounts of it in the fresh form is not advisable. On the other hand, because of its high moisture content and the perishable nature, the fresh tops are difficult to dry and ferment quickly. Drying of sugar beet tops may be a help for solving some of the problems of animal feeding and minimize such problems of disposal and pollution, at least in Kafr El-Sheikh province. It may offer a significant reduction in feed cost and minimize the requirements for expensive concentrate mixture. In Egypt, the locally produced forage quantity is not sufficient for feeding the livestock population; the thing that led to a forage gap in the feeding process. There is a gap between the available quantity of green forage and the required amount of animal feed. The gap between the availability and requirement of feed is wide and the estimated shortage is 3.1 million tons of total digestible nutrients per year. The forage gap, or the feed shortage, has been partially narrowed to become 2.42 million tons because of using new forage resources. For example, the sugar beet tops, contributing to solve this nutritional problem, added to the forage amount with a percentage of 6.19 % (*El-Shazly*, 1988; *Bendary et al*., 1999; *Eweedah*, 2000; and *AboSalim* and *Bendary*, 2005). As the various crop residues, particularly the sugar beet tops, contain a great ratio of moisture content, feeding these residues causes swelling and diarrhea to the animals eating them. So, it is necessary to dry the sugar beet tops in order to reduce their moisture content. Drying these by-products directly by the traditional sun-drying method is associated with drawbacks such as the requirement of large spaces and long drying time, contamination of crops by foreign material, crops being subject to insect infestation and susceptible to reabsorption of moisture. Moreover, this method does not produce uniform quality and is weather-dependent (*Bassey*, 1981; *Clark*, 1981; *Keddie*, 1981; *Maroulis* and *Saravacos*, 1986; *Lutz et al*., 1987; *Tiris et al*., 1995; *Fuller*, 1998; *El Sebaii et al*., 2002; *Madhlopa et al*., 2002; *Sarkar* and *Saleh*, 2002). Active solar driers are designed with external means like fans or blowers, for moving the solar energy in the form of heated air from the collector area to the drying beds. Agricultural rotary driers are single, double-, and triple-drum types. The inside of the drum may be fitted with flights that lift the material and shower it down through the heated air. Flight design varies with the material to be dried. Chains or other dividing devices may be fitted to the inside of the drum to divide materials that tend to clump as they pass through the drier. The rate of material movement through the drum is controlled by flight design, inclining the drum, or by the rate of heated air through the drum. The drum should rotate at such a speed that the material is spilled uniformly through the cross-sectional space of the drum. This procedure yields a product of uniform final moisture content (*Henderson* and *Perry*, 1976; *Tiris et al*., 1994; *Mumba*, 1996; *Condori* and *Saravia*, 1998; *Sarasilmaz et al*., 2000; and *Midilli*, 2001). The majority of active solar driers available in Egypt now suffer from a deficiency in the agricultural crop residues drying process because their design suits cereal and horticultural crops. Therefore this research aims at investigating the following:

1. Enhancing the thermal efficiency of the greenhouse type solar drier,
2. Modifying the design of solar drier to be suitable for drying crop residues and
3. Characterizing the performance of solar drier during hay making process.

Materials and Methods

Experimentation

The experiments were conducted for the sugar beet tops drying in April–May 2009 on the site of Animal Production Research Station (*Sakha, Kafr El-Sheikh*, Egypt) located at 31º 07' N latitude, 30º 57' E longitude and 20 m altitude (*Abou-Zaher*, 1998). The orientation of the greenhouse type solar drier was east-west during experimentation to maximize the incident solar radiation on the solar drier. On the basis of measurements, Kafr El-Sheikh, where the experiment was conducted, had about 12 h 30 min of daylight, with typically about 9 h per day of sunshine available for drying. Experiments were only conducted during daylight hours. All the experiments were started at 9.00 am and continued till 6.00 pm. For ease of construction, the greenhouse solar drier may be in a semi-cylindrical (Quonset) form as shown in **Fig. 1**. Basically, two types of studies were done on the solar drier: no load with fans switched off and fans operated with load conditions. In this study, experiments were done during two stages using the greenhouse type solar drier. The first stage of experiments aimed at improving the thermal efficiency of the solar drier space. The second stage aimed at modifying the design of greenhouse solar drier in order to be suitable for drying the studied sugar beet tops. This modification was performed because the design of the original greenhouse solar drier suits drying the field cereal crops; it is an active solar drier which is supplied with a suction fan in order to move the solar energy in the form of heated air from the drier area to the drying screen (**Fig. 1-A**).

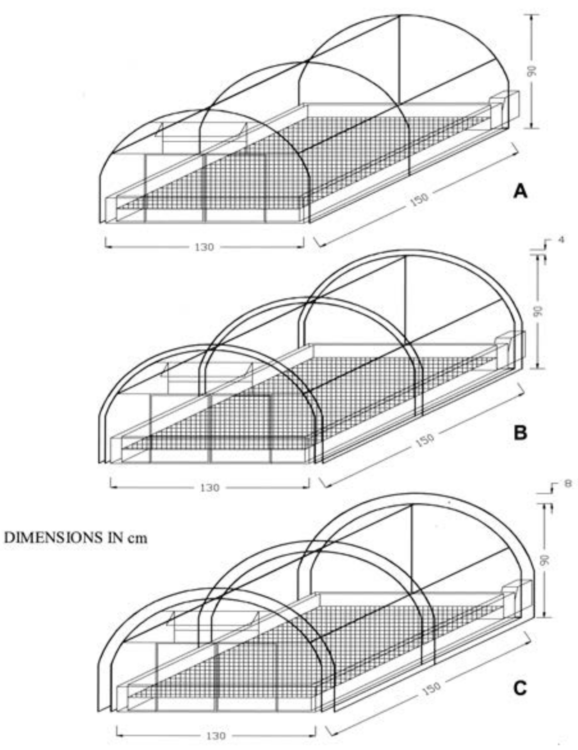
Test of the Drier Without Load and Fans Switched off

The experiment at no load was conducted for 30 days to measure the maximum temperature achieved by the collector space with a specific dead air space. During this study, the air intake window was kept open and neither fan operated throughout the day; hence, the greenhouse solar drier was used as a solar energy drier. Three structures of the greenhouse cover were used: a single layer plastic cover without dead air space (the distance confined between the outer and the inner cover); a double layer plastic cover with 4 cm dead air space and a double layer plastic cover with 8 cm dead air space. This dead air space serves as an insulator for increasing the heat balance inside the drier area. The clear plastic-film sheets Polyvinyl of 0.1 mm thickness was used as a cover in all the studied treatments. The working principle of the greenhouse type solar drier under no load condition is illustrated in **Fig. 1**. Double glazing plastic covered greenhouse traps the solar energy in the form of thermal heat within the dead air space and reduces the convective heat loss. The fraction of trapped solar radiation will heat the enclosed air inside the drier space. The greenhouse type solar drier was operated during the period from April 04-May 10, 2009 between from 09:00 to 18:00 h and the outer cover layer was changed alternatively for the three mentioned structures in order to know which dead air space achieves the highest air temperatures in the drier space (**Fig. 1**).

Test with Product Loaded in the Drier and Fans Operated

The proposed drier system was loaded with fresh sugar beet tops having an initial moisture content of 88.13 % db. Fresh sugar beet tops were obtained from the Delta Company of Sugar in Kafr El-Sheikh governorate, Egypt. The product was dried without doing any type of pretreatment. The fans were running throughout the experimental period. The greenhouse solar drier was essentially modified in order to dry the sugar beet tops. The solar drier was provided with an iron drum with a diameter of 50 cm and a length of 184 cm (volume = 0.36 m^3). For each of the experimental runs, the drum drier was loaded

Fig. 1 Schematic arrangement of the greenhouse passive solar drier under no load condition and fans switched off



A-single layer covered drier without dead air space;
B-double layer covered drier with 4cm dead air space;
C-double layer covered drier with 8cm dead air space

Fig. 2 Experimental setup of the greenhouse active solar drier with product loaded in the drier and fans operating condition: the double layer plastic covered drier with 4cm dead air space

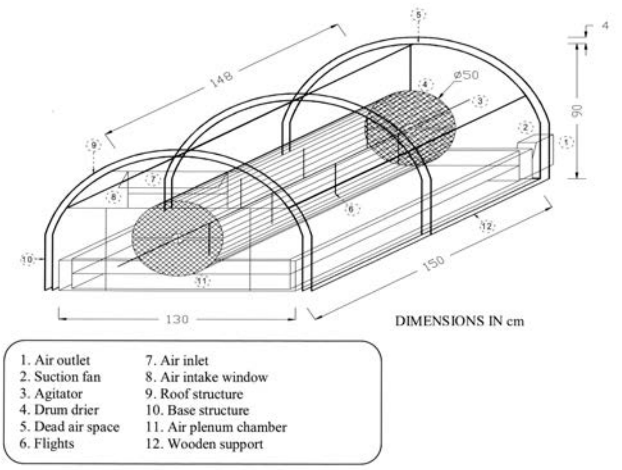
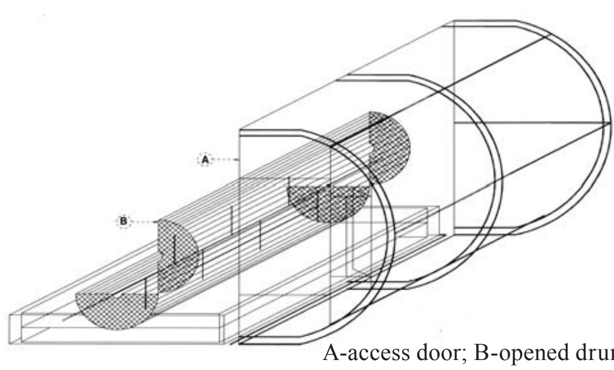


Fig. 3 Working principle of the greenhouse solar drier during loading and unloading sugar beet tops



A-access door; B-opened drum

to about 85 % from its capacity of sugar beet tops. The outside dimensions of the greenhouse drier were 1.3 m wide, 1.5 m long and 0.9 m high. The rough structure of the greenhouse type drier is depicted in **Fig. 2**. The drum circumference consisted of a number of steel bars evenly distributed spacing 1.5 cm in order to permit penetration of the air inside it. The sides of the circular drum were a net of steel. The drum was designed in a way that lets it opens to two equal haves using three joints and a lock. It is designed in such a way to load the product inside it and unload it after completing the drying process (**Fig. 2**). The drum is fixed and doesn't move but provided with an agitator that spins inside it in a circular movement so as to agitate the product using flights fixed on the agitator column. The agitator column is fixed on two bearings. The agitator moves via a pulley fixed at the back side of the agitator column, a belt and an electric motor. During a solar drying process, the drying air temperature depends on the value of the solar radiation. In all experiments described here, no additional heating energy was supplied to the samples apart from direct solar radiation. A multi-blade (8 blades) propeller type suction fan of 300 mm diameter connected to 0.25 kW electric motor with speed controller switch was used for air suction through the drier and installed in the wall opposite to the air inlet. Ambient air is sucked through the drier space and while passing it gains heat. This heated air is passed through the drying drum, where the product to be dried was loaded. Warm moist air is sucked from the drier, through the air chamber, by the propeller fan at the bottom of the rear side of the drier (**Figs. 2** and **3**).

Experimental Designs

With no load condition, the influence of three different dead air spaces of 0, 4 and 8 cm was investigated on the temperature increase and humidity reduction inside the greenhouse solar drier (with respect to the ambient conditions). This preliminary test was mainly carried out, before loading any extra product, to determine which dead air space will have the maximum temperature increase and the highest relative humidity reduction. Thereafter, the recommended roof structure (dead air space) will be taken into consideration for carrying out sugar beet tops drying. By virtue of this consideration, kinetic drying for the greenhouse type solar drying system was performed at drying airflow rates of 2.481, 5.473 and 8.862 m^3/min. In addition to these experimental conditions, the effect of drying airflow rate on the thermal efficiency of solar drier, moisture ratio and drying rate of sugar beet tops was studied. The three drying airflow rates were tested simultaneously under the same environmental conditions. Under each set of drying conditions, tests were conducted in triplicates.

Instrumentation and Measurements

Various measuring devices were used to investigate the effects of the environmental and operating parameters on the performance of the proposed solar drier. Measurements were taken each 1 h during the operation period of drying. The total incident solar radiation on a horizontal surface was measured by Rimco-Electronic Integrating Pyranometer located at Sakha weather station (make-Selbys Scientific Ltd., Oakleigh, Victoria, Australia). This instrument was chosen to give direct cumulative readings of total global radiation in mW h/cm^2. Measurements with this Pyranometer and the standard Kipp Solarimeter correlated significantly. The temperature (ºC) was measured using the thermocouple wires placed in the required measuring points. J-type iron-constantan thermocouples were used with a manually correlated digital thermometer (Model HH-25 and HH-26, USA), with reading accuracy of ± 0.1 ºC. Three thermocouples were evenly spaced in the greenhouse solar drier to measure the drying air temperature. The urgent measuring check points include ambient temperature, average greenhouse drier space and the temperature of dead air space. The typical method to measure humidity is the dry and wet bulb temperature method. Two thermocouples were hung inside and outside the solar drier to measure the wet and dry bulb temperatures. The relative humidity of air was calculated from measured wet and dry bulb temperatures using a psychometric chart. The velocity of air passing through the system and wind speed were measured by a 0-15 m/s range hot wire anemometer (Model 24-6111, Japan). This instrument was placed at air intake window plane of the tested drier when the fan was switched on. The output data of this instrument was multiplied by the area of the air intake window to give the drying airflow rate in m^3/s and then converted to m^3/min. Before the drying test was commenced, the initial moisture content of fresh sugar beet tops was determined. The samples were removed from the drum drier to determine their instantaneous moisture content every 60 min using an electronic balance with a precision of ± 0.01 g. Product samples of about 100 g were placed in the drum drier at various positions. During drying, the moisture contents at each time interval were calculated from both mass loss data and dry solid mass of the sample. At the end of the experimental drying run, the exact dry solid mass of the product samples was determined by the oven-drying method (AOAC, 1990). Drying tests were replicated three times at each drying airflow rate. The quantity of moisture content reported in the text can be represented on a dry basis and expressed in percentage (% db) unless and until it has been identified and mentioned.

Mathematical Modeling of Drying Curves

A mathematical model was developed for predicting the performance of this type of drier. The efficiency of solar drying systems can be evaluated based either on thermal performance or on drying rates of the products. In these conditions, the performance of a greenhouse type drier is described by an energy balance that indicates the distribution of incident solar energy into useful heat gain. A measure of drier performance is the drier efficiency, defined as the ratio of useful heat gain over any time period to the incident solar radiation over the same period. The instantaneous thermal efficiency of the solar air heater (η_{th}, %) was estimated using the following equation (Kadam & Samuel, 2006):

$$\eta_{th} = \frac{C_p m_a (T_d - T_a)}{A_s I} \times 100 \quad ....(1)$$

where c_p is the specific heat of air in J/kg. K; m_a is the mass flow rate of air in kg/s; T_a is the ambient air temperature and T_d is the drier air temperature. As is the surface area of the solar collector in m^2 and I is the solar intensity in W/m^2. Useful heat gain and available solar energy represent the numerator and denominator of **Eqn. 1**, respectively. The instantaneous dry basis moisture content M_d (% db) of the sugar beet tops at any time is defined by the following equation (ASHRAE, 2001):

$$M_d = \frac{m - m_d}{m_d} \times 100 \quad ....(2)$$

where m is the instantaneous mass and md is the fully dried mass. The drying rate (DR, %/min), which is another important factor in describing the characteristics of the drying process, is defined, with dry basis moisture content, by (Fatouh *et al.*, 2006):

$$DR = -\frac{dM_d}{d_t} = -\frac{M_{d,i+1} - M_{d,i}}{t_{i+1} - t_i} \quad .(3)$$

where $M_{d,i}$ and $M_{d,i+1}$ are the moisture content of sugar beet tops at the times t_i and t_{i+1}, respectively. The most relevant aspects of drying technology are the mathematical modeling of the drying process and the equipment. In order to achieve a set of equations which allow a proper description of the system, experimental results of moisture ratio versus drying time were fitted to the most important models to describe the kinetics of the drying process. The selected mathematical models are identified as follows:

The Simple Exponential Model:

$$MR = \frac{M_d - M_e}{M_o - M_e} = exp\,(-Kt) \quad .....(4)$$

where MR is the moisture ratio (decimal); M_d is the instantaneous moisture content (% db); M_e is the equilibrium moisture content (% db); M_o is the initial moisture content (% db); t is the drying time (min) and K is the drying rate constant (min^{-1}). In **Eqn. 4** the initial moisture ratio at drying time 0 becomes 1. This model in **Eqn. 4** (Lewis, 1921) has been applied to fit the drying data of sugar beet tops, after converting its form to the logarithmic form relating the moisture ratio (MR) and elapsed drying time (t) as follows:

$$Ln\,MR = (-Kt) \quad ....(5)$$

The Modified Simple Exponential Model:

$$\frac{M_d - M_e}{M_o - M_e} = A.\,exp\,(-Kt) \quad ....(6)$$

where A is the experimental constant (dimensionless). This model in **Eqn. 6** (Henderson & Pains, 1961) has been applied to fit the drying data after converting its form to the exponential form and calculating the constants K and A from the relationship between MR and t as follows:

$$MR = A.e^{(-Kt)} \quad ....(7)$$

Using non-linear regression and considering moisture ratio, MR, and drying time, t, as the regression variables, the parameters A and K in the empirical equations (**Eqns. 5** and **7**) were determined for each set of drying conditions. The coefficient of determination (R^2) was calculated for each model in order to test their accuracy in reproducing the experimental data. The higher values of the coefficient R^2 were chosen for goodness of fit (Akpinar *et al.*, 2006).

Sugar Beet Tops Hay

Chemical and mineral analyses for representative samples of fresh and dried sugar beet tops were carried out according to the standard procedures of the official methods (AOAC, 1980). Calcium, Zinc and Iron were determined by Atomic Absorption Spectrophotometer (238-Parken-Elmer Ltd., Melbourne, Australia). While Sodium and Potassium were determined by Flame Photometer PEP7. However, total Phosphorous was determined colorimitry using Molybden-blue reaction. All of the mineral analyses stated above were conducted in the Animal Production Research Laboratories (APRL, Sakha, Kafr El-Sheikh, Egypt).

Results and Discussion

Test of the Drier without Load and the Fans Switched off Condition

Neither fan operated throughout the experimental period, nor was it conducted with loading any product. Three solar air heating driers were investigated in this study. The experiments were carried out under climatic conditions of Kafr El-Sheikh city in Egypt. The experimental tests were performed during April and May of 2009. The results of the summer test at no load conditions are shown in **Fig. 4**, where the changes in drier temperature, ambient air temperature and the difference between drier and ambient air temperatures are shown. From the results of temperature profiles, it is apparent that the maximum air temperature inside the solar drier of 4 cm dead air space was 47.5 ºC. The ambient temperature ranged from

28 to 35.5 ºC. The temperature rise above ambient air was in the range of 9.5-17.5 ºC during the study period. Analysis of this figure reveals that the smallest temperature rise above ambient air of 9.5 ºC was in the solar drier of single layer cover (0 cm dead air space), whereas the highest temperature rise above ambient air of 17.5 ºC was in the solar drier of double layer cover with 4 cm dead air space. Comparing the data obtained from each drier, the average differences between drier and ambient air temperatures were 10.15 ± 0.57, 15.95 ± 0.95 and 13.90 ± 0.90 ºC for the solar drier of 0, 4 and 8 cm dead air space, respectively. The double layer covered solar drier with 4 cm dead air space achieved higher temperature rise by 57.14 and 14.75 % than the single and double layer covered solar drier with 0 and 8 cm dead air space, respectively. This confirmed the importance of dead air space in enhancing the thermal efficiency of the solar drier. Therefore, it can be deducted that the next drying tests will be directed at the double layer covered solar drier with 4 cm dead air space, which ensured the highest temperature rise among the other investigated structures. Very similar results were obtained with air relative humidity. **Fig. 5** shows the relative humidity variations at three different dead air spaces of the drier for a typical experimental period. As can be seen in the figure, the ambient relative humidity varied between 51 and 68 % with an average of about 61 %. Whilst the air relative humidity of the greenhouse type solar drier varied between 34

Fig. 4 Variation of temperature in the solar collector and ambient temperature during a typical experimental period under no load condition and the fans switched off at various dead air spaces

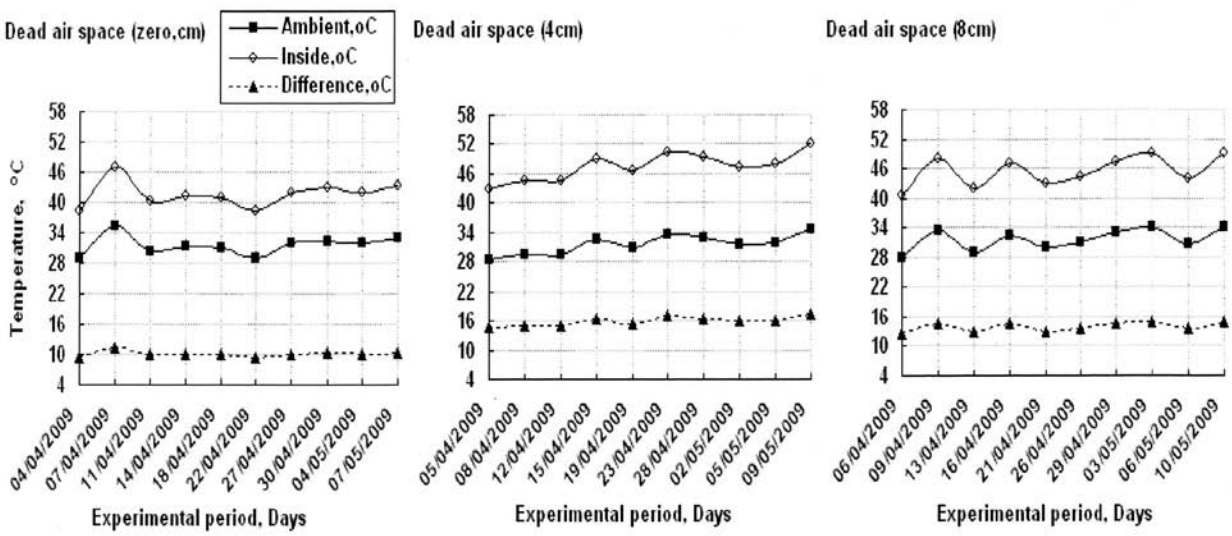
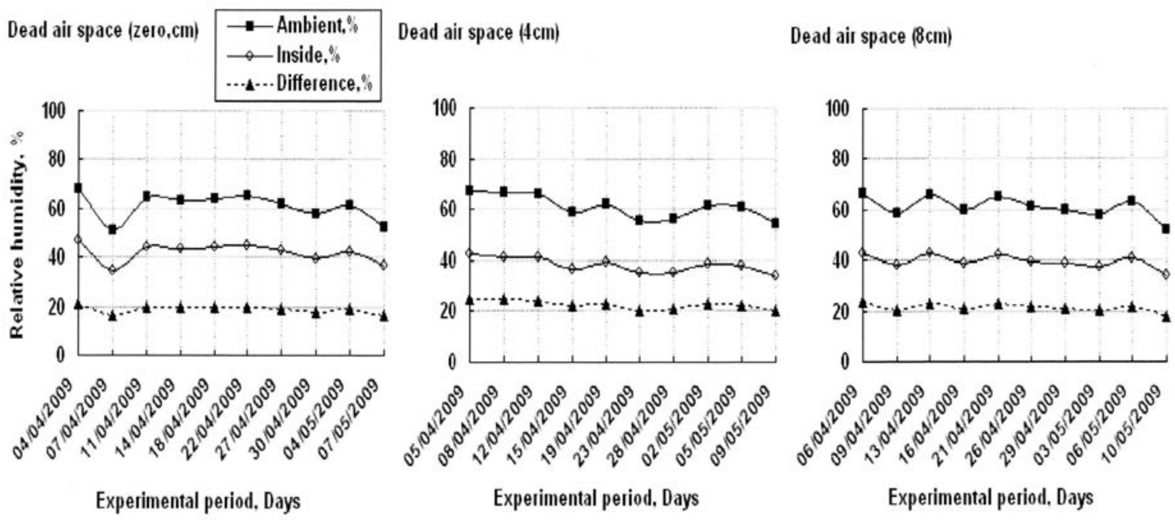


Fig. 5 Variation of relative humidity in the solar collector and ambient relative humidity during a typical experimental period under no load condition and the fans switched off at various dead air spaces



and 47 % with an average of about 40 %. The relative humidity reached its maximum of 42.05 % and minimum of 38.15 % for the single and double layer covered greenhouse solar drier of 0 and 4 cm dead air space, respectively. In comparison, the differences between drier and ambient air relative humidity were of 18.85 ± 1.6, 22.70 ± 1.6 and 21.40 ± 1.6 % for the single and double layer covered greenhouse solar drier of 0, 4 and 8 cm dead air space, respectively. This means that the double layer covered greenhouse solar drier of 4 cm dead air space achieved the highest difference between the drier and ambient air relative humidity. There is a very sharp decrease in relative humidity inside the solar drier of 4 cm dead air space. The relative humidity was reduced by 44.83, 59.50 and 54.11 % for the 0, 4 and 8 cm dead air space, respectively. As general, the ambient relative humidity decreased with the increase in the ambient temperature (**Figs. 4** and **5**). The double layer plastic covered greenhouse type solar drier of 4 cm dead air space could be recommended for conducting the drying experimentation.

Test with Product Loaded in the Driver and Fans in Operating Condition

In contrast to the above study, the fans operated all day. All the parameters monitored in the earlier study were monitored here also. Variation of temperature in the solar drier and ambient temperature with time of a day under load condition and the fans operating is depicted in **Fig. 6**. The maximum ambient temperature and the temperature attained by the solar drier was 40 and 60 ºC, respectively at 2.00 pm. The reductions in both temperatures, compared to those of the above study, were due to the operation of fans.

Fig. 6 Variation of temperature in the solar drier and ambient temperature with time of day under load condition and the fans operating

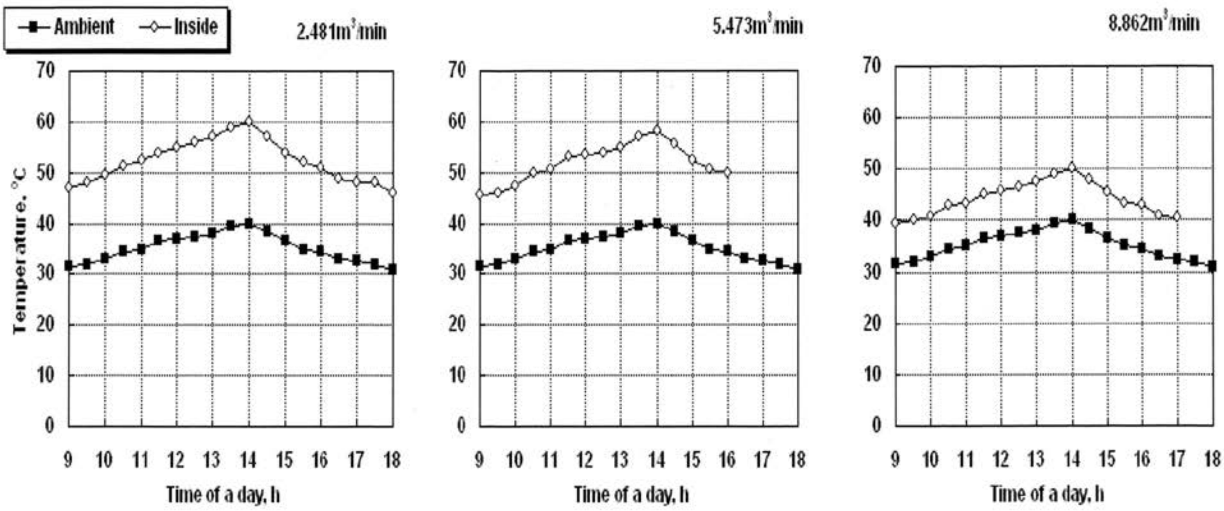


Fig. 7 Useful heat gain and available solar energy versus time of day at various airflow rates

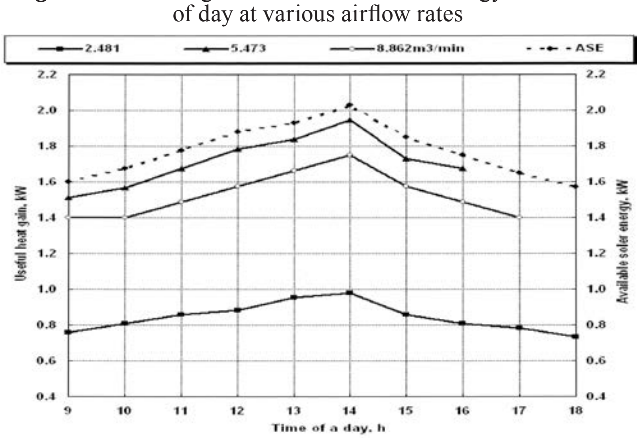
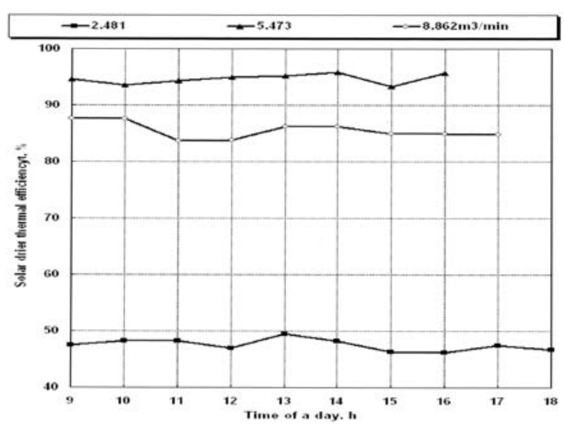


Fig. 8 Solar drier thermal efficiency versus time of day at various airflow rates



As the fans drew air through the solar drier, convective heat transfer took place between the drier space and the flowing air. However, it was observed that the temperature rises above the ambient air temperature were in the range of 8-20 ºC during 9.00 am to 6.00 pm. The average drying airflow rates of air inside the drier were 2.481, 5.473 and 8.862 m^3/min, and they were monitored in the air duct and suction point of the fans. Drying air temperature is an important parameter for drying applications. The solar drier air temperature was investigated for a wide range of airflow rates. **Fig. 6** shows the variation of inside (drier) temperature at different airflow rates. As expected, the inside temperature of the flowing air through the drier decreased with increased flow rate. For comparison purposes, the average drying air temperature recorded at the inlet of the drier was 52.3 ± 4.2, 51.9 ± 3.7 and 44.2 ± 3.2 ºC at 2.481, 5.473 and 8.862 m^3/min airflow rate, respectively. The profile of the temperature in the drier was nearly uniform and continued to have high values throughout the entire drying period, while the ambient temperature droped rapidly after solar noon. The condition of having constant temperature in the drier was required to satisfy the exponential model. Available solar energy and useful heat gain of the solar drier versus time of day at different airflow rates are illustrated in **Fig. 7**. They reached their maximum and minimum at the same time of the day, which was normal and demonstrated clearly that the temperature evolution was a function of instantaneous incident heat fluxes. Analysis of this figure revealed that the maximum available solar energy measured was 2.03 kW for a corresponding useful heat gain of 1.94 kW, values obtained at 2.00 pm. This indicated that the two parameters evolved in the same direction. However, it was observed that the available solar energy was in the range of 1.57-2.03 kW during 9.00 am to 6.00 pm. The useful heat gain was in the range of 0.73-1.94 kW during the same period of day. As can be seen in the figure, useful heat gain increased over time at different airflow rates inside the drier, during the first half of the day. This was caused by increasing the drying air temperature due to available solar energy increase, whereas the opposite was true for the latter half of the day. Furthermore, the daily average solar energy available was 1.77 ± 0.15 kW. At the same time, the daily average values of useful heat gain were 0.84 ± 0.08, 1.71 ± 0.14 and 1.52 ± 0.12 kW for 2.481, 5.473 and 8.862 m^3/min drying airflow rate, respectively. The useful heat gain reached its highest value of 1.94 kW at 2.00 pm and drying airflow rate of 5.473 m^3/min. The useful heat gain was higher for a drying airflow rate of 5.473 m^3/min by 103.6 and 12.4 % than that for 2.481 and 8.862 m^3/min, respectively. **Fig. 8** shows the comparison of solar drier thermal efficiencies at three different airflow rates inside the drier, for a typical experimental run of solar drying of sugar beet tops. To have a more global idea of energy transfers effectiveness in the drier, an instantaneous average thermal efficiency was calculated over all the duration of the drying for sugar beet tops. From the figure, it can be seen that the thermal efficiency of the solar drier was strongly dependent on the airflow rate. It was clearly seen that there was a nearly constant trend of the drier thermal efficiency during the drying period. Besides, the solar drier thermal efficiency varied from 46.15-95.80 % during the study period. The average thermal efficiencies were 47.53 ± 1.05, 94.67 ± 0.91 and 85.53 ± 1.42 % for 2.481, 5.473 and 8.862 m^3/min airflow rate, respectively. In comparison, the airflow rate of 5.473 m^3/min achieved the highest values of drier thermal efficiency and was higher by 99.18 and 10.69 % than that for 2.481 and 8.862 m^3/min, respectively. From the results of drier thermal efficiency profiles, it was apparent that this parameter was a measure of drying

Fig. 9 Variation of moisture content as a function of drying time at several airflow rates

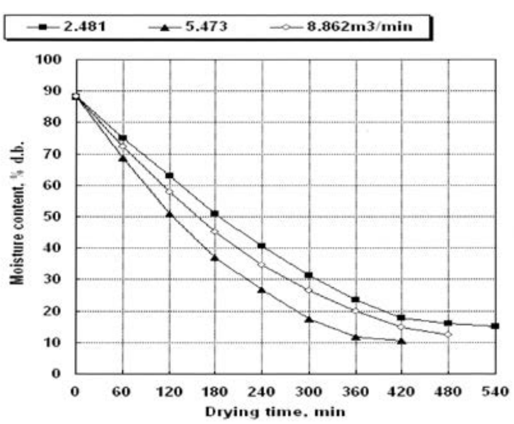
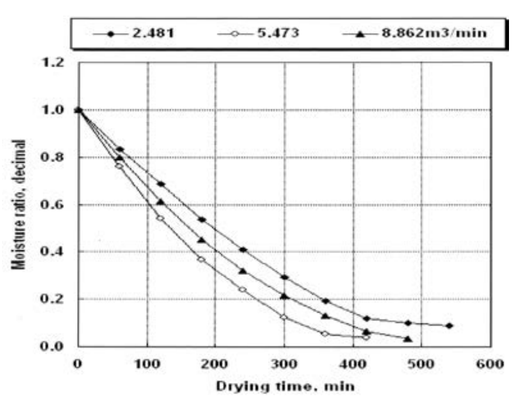


Fig. 10 Variation of moisture ratio with drying time of sugar beet tops at several airflow rates



potential of the air since it affected its ability to pick up moisture and to flow in and out of the drier. Being nearly constant, during the drying period, means that the drying potential of the drier remains, also, constant.

Drying Characteristic Curves

The changes in the moisture contents per amount of dry matter of sugar beet tops with time at different airflow rates are presented in **Fig. 9**. It is evident from the figure that the drying occurs in the falling rate period with a steep fall in the moisture content in the initial stages of drying, which becomes very slow in the later stages. This was because of the evaporation of surface moisture at the beginning of the process. It was known that as the moisture content of the product is reduced, more energy is required to evaporate the same amount of moisture from the product. For a fluctuating radiation intensity level, the moisture content of the sugar beet tops was reduced from an initial moisture content of 88.13 % db to the final value of 10.64 % db within one day with an effective drying time of 7 h as shown in **Fig. 9**. This meant that the entire moisture was removed from the product loaded in the solar drier in the first day itself. The effect of drying airflow rate was also presented in this figure. An increase in the drying airflow rate resulted in decreasing drying time as a result of increasing convective mass transfer between the drying air and the product (Kaya *et al.*, 2006). The drying time was not only dependent on the drying airflow rate, but also dependent on the drying air temperature. Therefore, the drying airflow rate of 5.473 m^3/min had the shortest drying time, which reduced the drying time by 22.2 and 12.5 % when compared to 2.481 and 8.862 m^3/min drying airflow rate, respectively. All of the drying airflow rates tested in the greenhouse solar drier gave short drying times and accomplished the drying process in the range of 7-9 h. As seen from **Fig. 9**, the shape of the characteristic drying curve is concave downwards. This is typical of the drying curves obtained during drying. The drying time was 540, 420 and 480 min at 2.481, 5.473 and 8.862 m^3/min drying airflow rate, respectively. It could be deducted that the drying duration required for the reduction of 88.13 % db moisture in the present drier was only 7 h. This clearly indicated the better performance of the designed drier. Confirming the previous explanation, the moisture content data at the different experimental modes were converted to the more useful moisture ratio expression. Mean dimensionless moisture ratio vs. time for the three drying airflow rates is shown in **Fig. 10**. As seen from **Fig. 10**, moisture ratio decreased exponentially with time. Difference between moisture ratios increased gradually from starting of drying. The decrease in drying airflow rate resulted in increase in the moisture ratio of sugar beet tops. The moisture ratio varied from 0.8349 to 0.0399. It was observed that the average moisture ratios were of 0.43 ± 0.32, 0.39 ± 0.35 and 0.40 ± 0.33 for drying airflow rates of 2.481, 5.473 and 8.862 m^3/min, respectively. Therefore, the drying airflow rate of 5.473 m^3/min achieved the lowest moisture ratios during the study period. For analysis of drying rates, the drying rate was determined from the slopes of the moisture content vs. drying time curves, at each measurement point. Improvement of drying rates was rather different at different drying airflow rates. **Figs. 11** and **12** show the drying rate versus moisture content and the variations of drying rate with moisture ratio of the tested samples at drying airflow rates 2.481, 5.473 and 8.862 m^3/min. The drying rate decreases continuously with time and decreasing moisture content or moisture ratio. Analysis of these figures reveals that the drying rates reach a maximum of 0.32 min^{-1} at drying airflow rate of 5.473 m^3/min, 0.26 min^{-1} at 8.862 m^3/min and 0.22 min^{-1} at 2.481 m^3/min. Be-

Fig. 11 Drying rates versus moisture content for sugar beet tops solar drying at several airflow rates

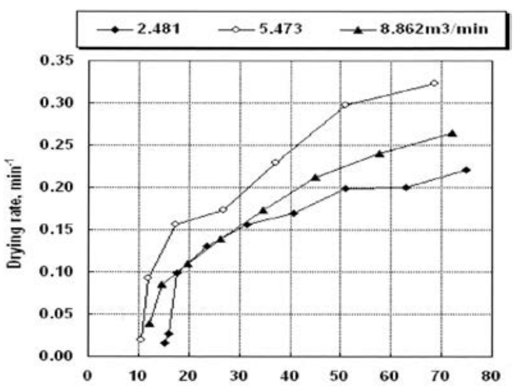
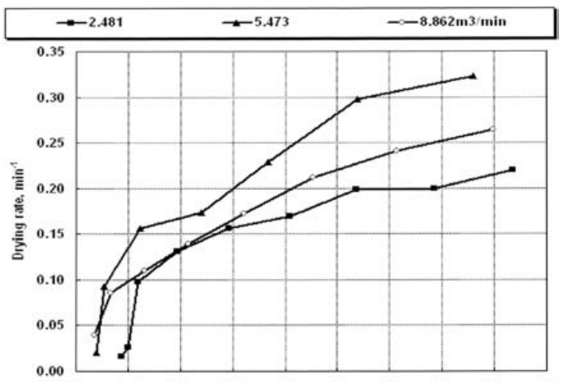


Fig. 12 The variation of drying rate as a function of moisture ratio at several airflow rates



sides, the increase in the drying rate was obviously noticed especially at the beginning of the drying period. As indicated in these curves, the whole experiment in this study came true in falling rate period. It can be seen (**Figs. 11** and **12**) that the drying airflow rate had a pronounced influence on the drying rate. As was expected, the drying rate increased greatly with increasing drying airflow rate. As illustrated in **Figs. 11** and **12**, the moisture decrease was slightly faster at 5.473 m^3/min than at 8.862 m^3/min. However, when the drying airflow rate shifted from 5.473 to 2.481 m^3/min, much larger difference in the moisture reduction rates was observed. The acceleration of the movement of water molecules at higher airflow rates also took part in a more rapid decrease of the moisture content. It is obvious that the average drying rate values among 2.481, 5.473 and 8.862 m^3/min drying airflow rate were determined as 0.135 ± 0.075, 0.185 ± 0.108 and 0.158 ± 0.079 (g water/g dry solid min), respectively. The values of drying rate increased by 37.04 % when the drying airflow rate was increased from 2.481 to 5.473 m^3/min. As previously described, the medium drying airflow rate of 5.473 m^3/min results in a faster drying rate at all times, and, hence, the increased drying rate effect was most pronounced for the intermediate drying airflow rates.

Modeling of Drying Curves

An efficient modeling of the falling rate period is a highly relevant task in a drying process. For that purpose, a wide set of solar drying curves were examined in the present work to describe the drying curves of sugar beet tops at different drying airflow rates. Two drying models have been used to describe drying curves. The model type, model constant or coefficient and determination coefficient (R^2) of two different models used for moisture ratio change with time are presented in **Table 1**. The criterion used for model selection was magnitude of average value of regression coefficients for each model. A nonlinear regression allowed us to fit each of the proposed models. Models with two, and even only one, coefficient were analyzed in order to optimize accuracy and analytical simplicity. From this perspective, the model that led to the highest R^2 for all drying airflow rates (with the available experimental data) was selected. This way, the simple model was found to show the most adequate behavior, with values of R^2 over 0.9791 along the whole drying airflow rate range. This model can be used to perform an accurate estimate of the moisture ratio of sugar beet tops at any time during the drying process along the whole drying airflow rate range considered in the experiments. Consequently, it might be stated that the derived simple model represented an adequate description of the solar drying of sugar beet tops at all drying airflow rates (R^2 average = 0.985). From the regression results, it can be seen that (**Table 1**) both of the parameters A and K increased and parameter R^2 decreased approximately linearly with the increase in drying airflow rate. Therefore, two relationships for the whole applied range of drying airflow rate during solar drying of sugar beet tops were represented as: for the simple exponential model,

$MR = \exp(-0.0056111t)$,
$R^2 = 0.9498$

and for the modified simple exponential model,

$MR = 1.1466 \exp(-0.006006227t)$,

Table 1 Drying constants at several drying airflow rates for both of the simple and modified simple exponential models

Drying airflow rate, m^3/min	Simple exponential model		Modified simple exponential model		
	K	R^2	A	K	R^2
2.481	0.0045	0.9911	1.1639	0.0049	0.9832
5.473	0.0072	0.9848	1.2806	0.0081	0.9742
8.862	0.0060	0.9791	1.3209	0.0068	0.9654

Table 2 Mineral composition of fresh and dried sugar beet tops

Treatments	Moisture content, %db	Dry matter, %	Ash, %	Oxalate, %	Composition of dry matter: Macro-elements, g/kg				Micro-elements, mg/kg	
					Ca	P	Na	K	Fe	Zn
Fresh sugar beet tops	88.13	11.87	26.16	4.27	6.73	1.92	4.30	36.55	100.56	45.44
Dried sugar beet tops: Low airflow rate (2. 481m^3/min)	15.09	84.91	27.22	3.47	5.00	3.23	3.59	37.62	176.60	88.68
Medium airflow rate(5.473m^3/min)	10.64	89.36	25.93	3.31	4.76	3.30	3.42	35.84	180.59	90.95
High airflow rate (8.862m^3/min)	12.28	87.72	26.41	3.37	4.85	3.27	3.48	36.50	179.12	90.11

$R^2 = 0.8715$.

The value of average regression coefficients revealed that the simple model fitted the experimental data very well and a reasonable agreement was found for the entire drying period. Therefore, the simple exponential model can be proposed to evaluate the moisture ratio of sugar beet tops for drying airflow rate (2.481-8.862 m^3/min).

Making Hay from Sugar Beet Tops

Chemical composition of fresh and dried sugar beet tops at different drying airflow rates are presented in **Table 2**. The dry matter content of fresh tops was 11.87 %. Such values were nearly close to that obtained by Eweedah (1986) who found that the dry matter content in sugar beet tops under Egyptian conditions was 8.53 %. However, the dry matter of fresh tops can be found higher value due to using different varieties under different environmental conditions. Fresh and dried sugar beet tops had almost the same values of ash content (**Table 2**). Such values were within the range of those reported by Eweedah (1986). The values of ash content of the dried sugar beet tops ranged between 25.93 to 27.22 %. As indicated in **Table 2**, the low Ca content of dried sugar beet tops and expected Ca percentage in hay compared with Ca content in fresh tops may be due to the losses of dry matter during drying and preparing hay, especially in green leaves rich in Ca. For comparison purposes, total oxalate content in the dried sugar beet tops ranged between 3.31 and 3.47 % on dry matter basis (**Table 2**). Similar results were reported by Bendary et al. (1992a). Values of K contents in dried sugar beet tops ranged between 35.84 and 37.62 g/kg dry matter similar to that reported by Bendary et al. (1992a). However, the variations in mineral content of the dried sugar beet tops were very adequate and advisable, when making hay for feeding animals, at drying airflow rate of 5.473 m^3/min compared with the two other airflow rates used in the present study. Since this drying airflow rate achieved the highest value of dry matter of 89.36 % and, consequently, the lowest one of moisture content of 10.64 % db for solar drying of sugar beet tops. According to these results, it could be concluded that drying of sugar beet tops alone may help in solving some of the problems of animal feeding such diarrhea and minimize such problems of pollution, using the solar drying method.

Conclusions

In this study, a proposed greenhouse solar drier was introduced, built and tested. The drying behavior of sugar beet tops at different operational conditions was investigated. Based on the work described here, it is possible to make the following conclusions:

1. The introduced modification made the temperature profile in the solar drier more uniform and continues to have high values throughout the entire sunshine period, a condition that is required to satisfy the exponential model.
2. The simple exponential model was the most suitable model for describing the drying curve of the solar drying process of sugar beet tops with R^2 of 0.9498.
3. The constructed prototype showed a maximum temperature increase of 17.21 ± 1.42 ºC (related to the ambient air temperature) and a reduction of the relative humidity (in terms of daily average) from 60.85 ± 4.74 % to 38.15 ± 3.01 %. This drying air temperature increase and the reduction of relative humidity (related to the ambient ones) ensured the feasibility of the device as a solar drier, presenting an advantage.
4. The drying airflow rate affected the rate of drying of sugar beet tops. The increase in drying airflow rate resulted in reducing, drastically, the total drying process period. In particular, required drying times to reach moisture contents of 15.09, 10.64 and 12.28 % db were 9, 7 and 8 h for 2.481, 5.473 and 8.862 m^3/min drying airflow rate, respectively.
5. In conclusion, the performance of the system is promising, showing a satisfactory pickup efficiency of 94.61 % at 9:00 am and more or less uniform during desiccant drying. If we decide to fabricate an air heater by using local materials, the greenhouse type solar collector must be double layer covered with 4 cm dead air space to get the highest efficiency. Finally, the developed drier could be well utilized in the domestic sector, and small and marginal farmers could also derive benefit from it.

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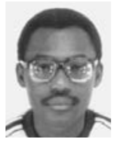
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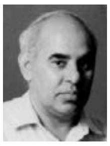
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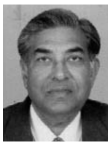
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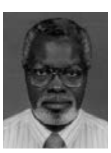
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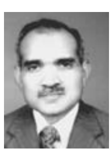
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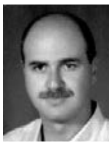
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a. Article must be sent on CD-R with MS DOS format (e.g. Word Perfect, Word for DOS, Word for Windows... **Absolutely necessary TEXT FORMAT**) along with two printed copy (A4).
b. The data for graphs and photographs must be saved into piecemeal dates and enclosed with the article.
c. Whether the article is a technical or popular contribution, lecture, research result, thesis or special report, the format must contain the following features:
   (i) brief and appropriate title;
   (ii) the writer(s) name, designation/title, office/organization; and mailing address;
   (iii) an abstract following ii) above;
   (iv) body proper (text/discussion);
   (v) conclusion/recommendation; and a
   (vi) bibliography
d. The printed copy must be numbered (Arabic numeral) successively at the top center whereas the disc copy pages should not be number. Tables, graphs and diagrams must likewise be numbered. Table numbers must precede table titles, e.g., "Table 1. Rate of Seeding per Hectare". Such table number and title must be typed at the top center of the table. On the other hand, graphs, diagrams, maps and photographs are considered figures in which case the captions must be indicated below the figure and preceded by number, e.g., "Figure 1. View of the Farm Buildings".
e. **The data for the graph must also be included. (e.g. EXCEL for Windows)**
f. Tables and figures must be preceded by texts or discussions. Inclusion of such tables and figures not otherwise referred to in the text/discussion must be avoided.
g. Tables must be typed clearly without vertical lines or partitions. Horizontal lines must be drawn only to contain the sub-title heads of columns and at the bottom of the table.
h. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
i. Indicate by footnotes or legends any abbreviations or symbols used in tables or figures.
j. Convert national currencies in US dollars and use the later consistently.
k. Round off numbers, if possible, to one or two decimal units, e.g., 45.5 kg/ha instead of 45.4762 kg/ha.
l. When numbers must start a sentence, such numbers must be written in words, e.g., Forty-five workers..., or Five tractors..."instead of 45 workers..., or, 5 tractors.

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