Review Article

Drudgery, Accidents and Injuries in Indian Agriculture

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Abstract: The Indian farming employs 225 million workforce to cover 140 million hectares of total cultivated land. In spite of rapid farm mechanization (e.g., 149 million farm machinery), the vast resource-poor family farming has primary dependence on traditional methods (e.g., 520 million hand tools and 37 million animal-drawn implements are in operation). The work drudgery, the traumatic accidents and injuries are the major concerns to examine options for ergonomics intervention and betterment of work in crop production activities. This review summarizes human energy expenditure in crop production activities, to assess the job severity, tools and machinery, and formulate the basis to reorganize work and work methods. While the farm mechanization is more in the northern India, the accidents were more in the villages in southern India. On average of the four regions, the tractor incidents (overturning, falling from the tractor, etc.) were highest (27.7%), followed by thresher (14.6%), sprayer/duster (12.2%), sugarcane crusher (8.1%) and chaff cutter (7.8%) accidents. Most of the fatal accidents resulted from the powered machinery, with the annual fatality rate estimated as 22 per 100,000 farmers. The hand tools related injuries (8% of the total accidents) were non-fatal in nature. In spite of the enactment of legislation, the shortcomings in production and monitoring of the machinery in field use may be responsible for the high rate of accidents (e.g., 42 thresher accidents/1,000 mechanical threshers/year in southern India). Due to the lack of technical capability of the local artisans, adhering to safety and design standards is impractical to the implements fabricated in the rural areas. The analysis emphasizes that the effective safety and health management may be possible through legislative enabling of the local infra-structure, such as block development authority and primary health services, to permeate occupational health and safe work practices in the farming sector.

Keywords: Farming drudgery and accidents, Farm machinery, Seedbed preparation, Transplanting, Weeding, Harvesting, Tractor accidents, Grain threshing, Chaff cutting, Pesticide application

Introduction

This India who had to beg with food bowl in the 1950–60's to feed her teeming millions, has become the world's second largest producer of rice and wheat, and transformed herself from a food importer to a food exporter today. The success story is a vivid example of the contribution of science and technology—advances in cropping systems, fertilizer

responsive high yielding crops, expanding irrigation, land reclamation and selective mechanization¹⁾. There is an apprehension that additional input has to come from better field operations in sustaining the self-reliance²⁾. This equation is confounded by the need for pragmatic approach to core safety and health issues of the vast population engaged in agriculture. Other concerns, such as challenges of population growth, abatement of child labour, environmental protection, zoonoses, rural health services, soil depletion, pest management, are in forefront to make sustainable agriculture.

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In light of the health and safety concerns in farming, this contribution reviews the work drudgery and severity categorization, and the traumatic accidents and injuries associated with the crop production activities, and elucidates the policy options for ergonomics intervention and betterment of work.

Farming Scenario, Tools and Machinery

Spread over 640,000 villages, India represents about 10% (225 million) of the total world workforce in agriculture. A variety of staple and specialty crops are grown in many settings, including resource-poor family farming, sharecropping, the large corporate farms, plantation, perennial crops, seasonal farming and urban farms. The small farmers including sharecroppers and tenants (70 million farm holdings having less than 4 ha of land) and the landless labourers constitute the primary workforce. Besides human power, 73 million draught animals (progenies of the milch animals) are the major source of farm power³⁻⁴. Of 140 million hectares (ha) of total cultivated land, about 63% of the area (88 million ha) is cultivated by draught animals, as against about 18% by tractors². In addition, the animal power hauls about 14 million carts, transporting 25 billion tonne-km of freight in rural areas.

The crop production encompasses seedbed preparation, sowing, planting, weeding, harvesting, threshing, livestock and materials handling, tools and machinery operation and maintenance, fertilizer and pesticide application, water lifting and irrigation, crop processing, storage and transport, and other jobs. A multitude of farm machinery including manually operated machines and hand tools, animal drawn implements, tractor and other powered machinery (Power-take-off—PTO shafts, hydraulic oil pressure, electrical power, engine power, ground traction) have been used.

- * Soil tillage machine (e.g., country plough, power tiller, disc harrow, tractor operated mouldboard plough, subsoiler, leveler)
- * Planting machines (e.g., seed drills, transplanter)
- * Cultivating machines (e.g., cultivator, weeder, rotary hoe)
- * Harvesting machines (e.g., combines, fibre crop harvesting machines, grain thresher, reaper, chopper, potato diggers)
- * Mechanical oil expellers
- * Chemical applicators (e.g., knapsack sprayer, duster, vehicle mounted sprayer)
- * Transport and elevating machines (e.g., tractor trailers, wagon, conveyors)
- * Post harvest machines (e.g., grain mill/rice huller, winnower, chaff cutter, sugar cane crusher, maize sheller)

* Hand tools (e.g., sickle, hoe, spade, pickaxe)

* Power system (e.g., electric motor, diesel engine, pump set).

About 150 million farm machinery and over 3 million tractors are in use, and nearly 200,000 tractors are introduced annually². With the present rate of tractorization, it would take at least 30 yr to cover the total cropping area under tractorized cultivation. The vast resource-poor family farming has primary dependence on manual methods, with estimated 520 million hand tools and 37 million animal drawn implements. Some farm operations are shown in Fig. 1.

Farming—Drudgery and Severity Categorization

Since the use of human power is extensive in operating farm tools and machinery, the assessment of work methods and tools is a potent factor to suggest performance improvement of the farmers. For example, minimizing the physical demands of work has a bearing in channelizing labour requirements at peak working seasons, and enhancing work efficiency. Here, we analyze the human energy expenditure in crop production activities (Table 1), which data have manifold utility in determining the job severity, assessing the impacts of tools and machinery, and formulating the basis to reorganize work. The intensity of work, referred to as work severity categorization, was expressed in terms of the energy demand relative to ones aerobic capacity ($V_{O2\ max}$)—light ($<25\% V_{O2\ max}$), moderate ($26\text{--}50\% V_{O2\ max}$), heavy ($51\text{--}75\% V_{O2\ max}$) and extremely heavy work ($>75\% V_{O2\ max}$)⁵⁻⁶.

The physical strain and fatigue might result in accidents and injuries, and therefore, the work levels that may be maintained daily on a regular basis should be optimized. Nag *et al.*⁷ and Nag and Chatterjee⁸ suggested that the work levels for 8 hourly activities for men and women should not exceed beyond 35 and 28% of one's aerobic capacity. To avoid accumulation of fatigue, it is obvious to formulate work-rest sequence in accordance with the types of physical activities performed. Nag and Pradhan⁹ brought out an example of the work-rest ratio in hoeing tasks. The O_2 deficit of a person (e.g., 5.8 l) during maximal work was taken as the indicator of energy reserve. The reserve remains undisturbed as long as the work is aerobic (e.g., 1 to 1.25 l/min). If the V_{O2} demand in hoeing tasks varies from 1.5 to 1.9 l/min, for the excess V_{O2} demands of 0.5 to 0.7 l/min the energy reserve would last about 10 min. At this point, the fatigue will ensue, unless the reserve is replenished by work breaks. The duration of rest can be determined by subtracting the resting V_{O2} from the assumed aerobic level of 1.0 to 1.25 l/min. This leaves the remaining V_{O2} requirement (0.8

Fig. 1. Farm operations.

Seed bed preparation using (a) country plough and (b) tractor, (c) pedal threshing, (d) grain threshing by animal treading, (e) harvesting paddy, (f) inter-row subsoil leveling by wooden rake, (g) power tiller operation, (h) load carrying for fuel wood collection, (i) chaff cutting, (j) winnowing.

Table 1. Energy demand and work severity categorization of farm operations and activities*

Farm operations and activities	Energy demand (kJ/min)	Work Severity	References
Ploughing (Country plough, Mouldboard plough)	13.9 – 28	moderate to extremely heavy	Nag <i>et al.</i> ⁷⁾ , De and Sen ¹¹⁾ , Gite ⁶¹⁾ , Nag and Chintharia ⁶²⁾
Leveling soil by laddering or wooden rake	9.8–16		
Digging soil using a hoe, bund trimming (wet and dry land)	19.6 – 35.5 (13.5 – 25.5)		
Hoeing, low lift (41–70 stroke/min); High lift (21–35 stroke/min)	20.7 – 39		Nag and Pradhan ⁹⁾ , Pradhan, <i>et al.</i> ⁴¹⁾
Tractor-empty trailer on bitumen road (6–10 km/h)	9.9 – 13.6	light to moderate	TNAU ¹⁴⁾
Tractor-cultivating (3.0–6.0 km/h)	10.2 – 15		
Tractor-disc ploughing (2.5–3.5 km/h)	11.7 – 16.7		
Power tiller-transport on bitumen or farm road (3.5–5.0 km/h)	10.8 – 12.8	moderate	Pawar and Pathak ⁶³⁾ , Tiwari and Gite ⁶⁴⁾
Power tiller-rotapuddling (1.1 to 2.3 km/h)	11.7 – 18		
Power tiller-rotatilling in tilled and untilled field (1.5–2.4 km/h)	13.3 – 20.1		
Sowing	7.0 – 16.7	light to moderate	Nag and Dutt ¹²⁾ , TNAU ¹⁴⁾
Paddy seeder (manual)–4, 6 and 8 row	24.9 – 31.7	heavy to extremely heavy	
Direct paddy seeder (manual)	25.1 – 26.8		
Germinating seeder (CRRRI type)	27.4 – 41.4		
Germinating seeder (IRRI type)	29.3 – 51.1		
Paddy transplanter (powered)	23.3 – 25.1	heavy	
Transplanting seedling (by hand) on puddled field	13.1 – 16.4 (11.0 – 15.5)	moderate	Nag and Chatterjee ⁸⁾ , Nag and Dutt ¹²⁾
Weeding (using hand tool) in bent and squat posture	9.3 – 14.4 (9.6 – 18.5)	light to heavy	Nag and Chatterjee ⁸⁾ , Nag and Dutt ¹⁷⁾
Weeding-single row, multiple sweep weeder	8.9 – 15		
Weeding-blade and rake weeder	10 – 29.2		
Weeding-projection finger weeder (dry and wet land)	12.2 – 26.3 (11.5 – 22)		
Weeding-single, double and triple sweep wheel weeders	11.2 – 25.9		
Weeding-wheel hoe weeder	13.6 – 28.2		
Cono weeder (manual)	25.4 – 27.5	heavy	TNAU ¹⁴⁾
Fertilizer/pesticide broadcasting	5.5 – 12.7	light to moderate	Nag <i>et al.</i> ⁷⁾ , Ghugare <i>et al.</i> ³⁹⁾
Knapsack spraying of pesticides	3.1 – 11.6		
Uprooting seedlings by hand (bent and squat posture)	7.7 – 19.7 (6.8 – 19.7)	moderate to heavy	Nag and Chatterjee ⁸⁾
Harvesting paddy using sickle	6.8 – 13.7 (8.2 – 17.4)	light to heavy	Nag <i>et al.</i> ⁷⁾ , Nag and Chatterjee ⁸⁾ , Gite and Agrawal ¹⁴³⁾
Plucking vegetables	8.6 – 12.1		
Cutting sugarcane	10.6 – 13.9		
Self-propelled paddy harvester	23.7 – 27.4	heavy	TNAU ¹⁴⁾
Load carrying on head (20–25 kg)	10.1 – 22.4 (10.4 – 25.7)	moderate to extremely heavy	Ramanathan and Nag ⁶⁵⁾ , Singh and Kaul ⁶⁶⁾
Load carrying on head (60–80 kg)	39.7 – 47.6		
Load carrying on yoke (60–75 kg)	32.2 – 42.2		
Threshing paddy by beating	17 – 21.5		Nag and Dutt ¹²⁾
Threshing paddy by pedal thresher	21.0 – 34.2		
Winnowing (squat and stand)	4.5 – 20.1 (6.1 – 11.1)	light to moderate	Nag <i>et al.</i> ⁷⁾ , Nag and Chatterjee ⁸⁾
Irrigation work (water channeling in the field)	7.5 – 14.1		
Irrigation work (water lifting using swing basket)	17.6 – 26.5	moderate to heavy	
Pounding grain	13.2 – 25.2	moderate to extremely heavy	
Walking on puddled field (1.1–2.3 km/h)	11.3 – 15.7 (8.5 – 14.5)	light to moderate	
Spreading grains, vegetables on the floor	(12.8 – 17.3)	moderate to heavy	

*: women data are presented in the parenthesis.

to 0.9 l/min) to replace the energy reserve, requiring about 6 to 7 min. This derivation evolves that a cycle of work at a V_{O_2} of 1.5 to 1.9 l/min may be organized into periods of 10 min work and 7 min rest, and thereby, the energy reserve is replenished. This approach can be utilized to arrive at work-rest ratio in diverse activities.

Seedbed preparation, sowing and transplanting

The seedbed preparation involves selective field tasks such as to breaking up a hard surface with a plough (country/mouldboard plough, tractor, power tiller implements), breaking down the ploughed surface using a cultivator or harrow, and inter-row soil preparation to grow crops¹⁰. With manual methods, nearly 120 man-hours are required per ha of land preparation. The severity of seedbed preparing activities, like ploughing, hoeing, bund trimming (Table 1) vary from moderate to extremely heavy, which have primarily been done by the men-folks¹¹. The tractor and single axle power tiller operations are categorized as moderately heavy.

The sowing of seeds (broadcasting or dibbling of seeds by hand, uprooting and transplanting of seedlings) requires about 20 to 30 man-hours per ha of land, and that takes away about 8% of total man-hours in farming. In dibbling, a hole is made in the soil by index finger or dibbling pegs, seeds dropped in it and covered with soil in bent or squat posture. The seeds are also sown by opening a furrow and putting seeds in it. The manual broadcasters and dibblers give uniform application of seeds/fertilizer over an area. The seed-cum-fertilizer drills, mounted on two wheels, give larger coverage per unit time, however, the size and position of the handle, and the push/pull force required to operate the drills are important design parameters. Both manual and mechanical types of rice transplantors (4 to 10 row type) are also available today. For sowing and transplanting tasks in the puddled field, the workers knee deep in mud have high postural load, with 20 to 25% higher energy demand than that required on the dry surface¹². Sen and Chakraborti¹³ proposed float seat to work in the watered field; however, its efficacy is yet to be examined. The comparison of different paddy seeders^{12, 14} indicated the limitation that while the seeders gave larger coverage of land, these were about 2.5 to 3 times higher energy demanding than in manual transplanting, and categorized as extremely heavy task (Table 1). There is a scope of ergo-design improvement of the seeders, with suitable design changes to use draught animal power in its operation.

Weeding and intercultivation

Weeding and intercultivation takes away nearly 15 to 20%

of the total man-hours involved in crop production. Since the period available for weeding is limited due to high soil moisture situation, the efficient weeding methods (e.g., mechanical, chemical and biological) are necessary. The weeding by hand or using hand tools such as hand hoe, weeding hook are widely used in rural India. In the dry land, the workers remove weeds by sitting on the ground with one or two legs flexed at knee, whereas in the watered land, the workers stoop to remove weeds. Each way of doing the weeding tasks exerts postural stress. Different kinds of manual weeders (e.g., projection finger weeder, V-blade hoe, Dutch hoe, blade and rake type, multiple sweep wheel type, wheel hoe type) are used in pulling or pushing modes (5 to 20 kgf). Since the weeder designs have been evolved through local practices, there are lots of variations in technical specifications^{15, 16}. The use of weeders was generally categorized as light to heavy work, depending upon the soil condition. The wheel hoe weeder (85 sqm/h) appeared to have highest area coverage, whereas in other types of weeders, the area coverage ranged from 25 to 65 sqm/h¹⁷. Based on the work output and physiological responses, it was suggested that the wheel hoe weeder that consists of one or two small iron band wheel(s), a blade, a frame and a handle, might replace the manual weeding.

Irrigation

Irrigation has made intensive cropping possible in arid and semi-arid regions, however, the irrigated to arable land in India is only about 20% and the most cultivation depends on the monsoon rainfall pattern. Since time immemorial, various human and animal powered devices (e.g., swing baskets, counterpoise water lifts, water wheels, chain and washer pumps, reciprocating pumps) have been used for irrigation of crops and rural water supply. For example, a swing basket operated by two people, is used for lifting the water from irrigation channel to the field. The capacity of the basket is about 4 to 6 l and the frequency of operation is about 15 to 20 swings/min. The operators work at right angle to the direction of basket motion, and the operators have to bend, twist, straighten up and swing the basket. The severity of the most manual methods of water lifting was categorized as heavy work. With the availability of electrical or engine powered pump sets, there is a large-scale endeavour to exploit river water and to make available irrigation channels at every corners.

Harvesting

Harvesting of rice, wheat and other crops takes away nearly 10% of the total man-hours used in crop production. A sickle

is the most common harvesting tool—it consists of a curved serrated blade attached to a wooden handle, however, with a variety of designs¹⁸). The average area (paddy/wheat) harvested by a person using a sickle ranged from 80 to 90 sqm/h. The sickle ergonomics, blade geometry, blade serration and material, handle shape and size, and mechanics of operation have their effects on work performance^{19–20}). The paddy/wheat harvesting in hot climate causes a considerable cardio-respiratory and thermo-regulatory strain²¹). Singh and Singh¹⁹) observed that a serrated sickle gives better performance than a plain one with shearing force at the cutting edge. Nag *et al.*²²) compared nine different sickles for wheat harvesting, and suggested a sickle having 200 gm weight, total length 33 cm, handle length 11 cm, handle diameter 3 cm, radius of blade curvature 15 cm, blade concavity 5 cm, serrated sickle: tooth pitch 0.20 cm and tooth angle 60°, and ratio of the length of cutting surface to chord length 1.20.

Post harvest operations

The post harvest operations, by their very nature, include crop gathering and removal, which require the use of manual and mechanical winnowing, raking, shelling, decortications, hulling, peeling, cutting, slicing, fiber extraction, etc.²³). Many of the post harvest operations have traditionally been performed on the farm itself, by labour intensive methods, and with a very low output. The winnowing is a process to separate grains from chaff by blowing air, using a hand fan or a pedal-or motor-driven fan. In manual methods, the whole content is thrown up in the air, and the differential momentum separates the grain and chaff out.

With the introduction of machinery and devices (e.g., groundnut decorticator, rice and soybean huller, areca nut dehuller, potato peeler, potato/cassava slicer, coconut dehusker, castor sheller), there is a substantial increase in output. For example, the traditional hand and foot operated hullers have been fast replaced by motorized rice mills. In grain mill/rice hullers, the power is given from a motor with a flat belt or V belt. This type of open power transmission causes accidents by entanglement of loose cloth, hair or other body part. Decortications involve breaking of shells and removal of seeds (e.g., groundnuts, castor beans). A groundnut decorticator separates kernels from pods. In manual decortications (about 2 kg of pod shelling/h) the workers complain of bodily discomfort due to the long hours of sitting or squatting posture. Oscillating or rotary-mode decorticators have an output of about 40 to 60 kg of pods/h. Shelling and hulling refer to separation of seed coat or husk from the inner portion of the grain (e.g., paddy, soybean).

In some grains, such as pigeonpea, the seed coat or husk is tightly attached, and the removal of the husk in such cases is called dehusking. In many of the post harvesting machines, the forces required in operating the machines are the limiting design factors. The handle design and feeding platform are important ergonomics consideration.

Accidents and Injuries

The accidents and injuries are natural hazards to every one working in the farm environment and these happen as a culmination of multiple factors, e.g., man, machine, crop, toxic chemicals or environmental factors. Since the farming sector is unorganized in character, there is an absence of nationwide repository on farm related accidents and injuries, which could be useful to quantify the health and safety, and economic consequences. Verma *et al.*²⁴) surveyed power thresher incidents in the Punjab state (northern India) and reported that about 73% of the incidents were due to human factors, 13% (machine factors), and the remaining 14% were due to crop and other factors. Mohan and Patel^{25, 26}) reported 576 farm injuries from nine contiguous villages outside Delhi (northern India) in a one year period; 87% were minor, 11% moderate, and the remaining 2% were severe injuries. The maximum injuries occurred while working with spades (24%), followed by sickles (23%), manual and power operated chaff cutters (11%), bullock carts (6%), tractors and diesel engines (5% each). The All India Coordinated Research Projects (AICRP) on human engineering and safety in agriculture reported accident and injury data (1995–1999) from forty-four sample villages of eastern, southern, central and northern regions^{14, 27–29}). While the information from the western regions is not available, these reports appeared to be the most comprehensive accident treatise, so far. The summary statistics of the data are given in Table 2.

The farm mechanization appeared to be more in the villages in the northern India, followed by the villages in central, southern and eastern India. While the rate of accidents per 1,000 workers per year ranged from 1.90 (central India) to 3.64 (southern India), the data expressed per 1,000 machines/yr showed a remarkably high accident rate in the villages in the southern India. The tractor accident appeared to be highest in the eastern regions, followed by the central and southern India. In spite that the tractor population is large in the northern India, the accident rate appeared to be the lowest. Importantly, most of the fatal accidents resulted from the powered machinery, and the hand tools related injuries were non-fatal in nature. The region-wise variations in the incidences of accidents are probably due to factors, such as skill of workers,

Table 2. Farm tools and machinery population, and accidents per unit village in different regions

	Eastern India (Mean $\pm$ SD)	Northern India (Mean $\pm$ SD)	Central India (Mean $\pm$ SD)	Southern India (Mean $\pm$ SD)
Total cultivated area (ha)	376 $\pm$ 184	877 $\pm$ 438	622 $\pm$ 348	628 $\pm$ 420
Agricultural workers	1236 $\pm$ 478	1195 $\pm$ 112	1523 $\pm$ 1220	2210 $\pm$ 912
Male/Female ratio	1:0.91	1:0.80	1:0.93	1:0.78
Farm machinery (tractor, chaff cutter, thresher, etc)	222 $\pm$ 55	1624 $\pm$ 1388	501 $\pm$ 333	325 $\pm$ 209
Hand tools (sickle, spade, etc.)	1200 $\pm$ 310	2037 $\pm$ 2106	2885 $\pm$ 1827	3058 $\pm$ 1339
Accident rate/1,000 workers/yr	2.18	2.52	1.9	3.64
Machinery related accident rate/1,000 machines/yr	3.09	1.33	3.88	22.12
Tractor accident rate/1,000 tractors/yr	55	1.31	25.83	14.33
Chaff cutter accident/1,000 chaff cutter/yr	3.5	0.94	1.91	8.94
Thresher accident/1,000 thresher/yr	2.02	1.8	9.4	41.85
Sugar cane crusher accident/1,000 sugar cane crusher/yr	13.33	1.31	—	61.33
Sprayer accident/1,000 sprayer/yr	0.97	1.73	0.45	14.47
Hand tools related accident rate/1,000 hand tools/yr	0.39	0.02	0.15	0.42
Other accidents (snakebite, agro-chemicals, etc)/1,000 workers /yr	1.12	0.7	0.23	0.38
Fatal accidents (%)*	4.6	22	9.2	4.3
Children (<15 yr) involved in accidents (%)	10.5	3.2	4.9	2.3

Based on TNAU¹⁴), CIAE²⁷), PAU²⁸), OUAT²⁹), ICAR⁴⁷). *: Percentage was calculated from the total number of fatal and non-fatal accidents, i.e., 131, 100, 76 and 414 for the above four regions respectively.

Fig. 2. Distribution of traumatic accidents with different farm machinery and activities.

type of machinery used and participation rates.

The tractor and tractor implements, thresher, sprayer, sugar cane crusher, chaff cutters accidents accounted for 70% of the total farm accidents (Fig. 2). The tractor incidents were highest (27.7%), followed by threshers (14.6%), sprayer/

duster (12.2%), sugar cane crusher (8.1%) and chaff cutters (7.8%). The hand tools related accidents accounted for 8% of the total accidents. The primary events of farm incidents (fatal and non-fatal) were (a) entanglement of loose garment, hair or limbs, in moving machines, (b) cut with hand tools,

(c) fall from tractors or into wells, (d) run over by tractor, (e) overturning of tractor, (f) hit by moving machine parts or falling objects, (g) snakebites, (h) electrocution due to live electric wires, etc. Most of the sugarcane crusher accidents happened when the operators were lubricating the transmission components when the crusher was in operation. Tiwari *et al.*³⁰⁾ detailed the AICRP data of eight villages from central India, and recorded the overall incidence of accidents as 1.25/1,000 workers/yr. The males constituted 93% of the victims and the highest concentration of injuries occurred among the farmers of 30 to 39 yr of age, and the remaining 7% were females. The men-folks generally operate the injury-prone machinery, and the women-folks are involved in activities like transplanting, interculture, harvesting, with the use of hand tools.

From the AICRP data, the annual fatality rate was estimated as 22 per 100,000 farmers, which was comparable to those in the countries like USA and Australia. Rautiainen and Reynolds³¹⁾ reported agriculture as one of the most hazardous industries in the USA, where the fatality rate remained as 22 per 100,000 workers through the 1990s. The leading causes of fatality in crop production were machinery and motor vehicles. The farming fatalities in Australia were reported as 20.6 per 100,000 workers³²⁾. Pickett *et al.*³³⁾ reported an annual fatality rate of 11.6 per 100,000 farmers in Canada, agriculture being the fourth most dangerous in terms of fatal injury, behind mining, forestry and construction.

Tractor accidents

Tractor, apart from its use in farm activities, it is a common mode to transport agricultural materials as well as people in the rural areas. The types of tractor-related incidents recorded are the roll over/overturning, falling from the tractor and run over, and also the incidences of PTO entanglements^{14, 27–29, 34)}. The improper tractor and tractor trailer stability and lack of driving skill and maneuvering of farm implements by the operators have been reported as the major reasons of accidents^{30, 34)}. When the tractor moves onto a slope and/or an implement is mounted, the tractor may move toward an unstable position (e.g., when the tractor center of gravity (CG) moves beyond the stability baseline) and result in roll over. The tractor operation often requires a large braking force (600 N or more) to be exerted by an average operator weighing 50 to 60 kg. Also the locations of seat and controls on the tractor makes difficult for one to operate the controls in emergencies, and/or egress from the tractor. Since no rollover protective structures have been provided on the tractors, the operators are at risk of being crushed during a rollover. Besides, the tractor stability depends upon the

centrifugal force that increases in direct proportion to the radius and a square of the angular velocity of the turning tractor. Another stability factor is the rear-axle torque that involves energy transfer between the tractor engine and the rear axle of a two-wheel-drive tractor. Engaging the clutch results in a twisting force (torque) to the rear axle and transferred to the tractor tyres. The rear axle is said to be rotating about the tractor chassis. If the rear axle is unable to rotate at a situation, the chassis rotates about the axle. This reverse rotation may result in lifting the front end of the tractor. As a result, the CG point may pass the rear stability baseline, causing the tractor to continue rearward from its own weight until it crashes into the ground or another obstacle. The drawbar leverage is another principle of causing tractor overturns. When a two-wheel-drive tractor pulls a load, essentially the load pulls back and down against the forward movement of the tractor. With heavier the load, the higher the angle of pull is created between the ground's surface and the point of attachment of load on the tractor, and the more leverage the load has to tip the tractor rearward.

The tractor run over incidents are (i) the tractor operator or the extra rider falls off the tractor, and (ii) a person already on the ground (children playing around the farmstead) is run over by the tractor. In spite of regular maintenance of battery, the self-starter is an inherent problem with the tractors. These machinery are operated at lower rpm of engine, than required for charging of battery through the dynamo due to limitations of field operations. Often the operators prefer to put the tractor on ramp and start the tractor by pushing, which procedure is risky to cause run over accidents. Lack of periodic maintenance also leads to accidents like breaking of the axle, faulty operation of clutch and brake, etc. The incidences of tractor accidents might partly due to the improper coupling and uncoupling of implements and/or lack of training to the operator doing the hitching job³⁰⁾. Tractor is the only vehicle having no fuel meter. Therefore, only way is to open the cap of fuel tank and look into it. During night, often the operator gets injured as they look in to the fuel level, igniting a cigarette lighter. Also, there are no lights or turning indicators at the rear of the trailer. The hitting of the trailer at the rear side by the fast moving vehicles during night is common.

Grain threshing and chaff cutting hazards and accidents

The age-old methods of threshing of grain from the paddy pinnacle are—rubbing the earheads with one's feet, beating of the harvested crop on a plank, animal treading, etc. The mechanical as well as pedal threshers are available today

for threshing of paddy and wheat crops. In manual threshing by beating, one can separate about 100 kg of grain/h, whereas by using a pedal thresher (oscillating or rotary mode) one can separate about 150 kg of grain/h from medium sized paddy/wheat plants¹²⁾. However, the pedal threshing is a strenuous activity with high muscular strain due to speedy pedalling and holding of paddy plants on the rolling drum. The ergonomics improvement in the pedal thresher might allow a rhythmic legwork in sit-stand position; in addition, the weight of the rolling drum at about 8 kg might be comfortable to the user¹²⁾.

For threshing of groundnut and maize, the hand/pedal-operated devices are available. One can hold a tubular maize sheller that weighs about 300 gm on one palm, and rotate to separate the maize grains (about 25 kg/h) from the cobs. The hand operated rotary type maize shellers have higher work output (about 85 kg/h). However, the force exertion in operating the handle, length and size of the handle, and speed of operation are the critical points in these types of devices.

For paddy and wheat crops, the mechanical threshers have been widely used in the green revolution areas. The machinery consists of a prime mover, a threshing unit, a winnowing unit, a feeding unit and a grain outlet. The self-propelled combines are a combination of a harvester and a thresher unit. The mechanical threshers, chaff cutters and winnowers are known for its high accident risks, due to lack of adhering to safety gadgets on the machinery^{24, 25, 35)}. Mohan and Patel²⁵⁾ reported the incidences of moderate to severe injuries as 13.1 accidents/1,000 threshers/yr. A very high incidence of grain thresher accidents have been reported from the southern India (41.85 accidents/1,000 threshers/yr (Table 2).

In a mechanical thresher running at full PTO speed, the farmer holds onto crop material to put into the machine. The accidents occur when crop material plugs the intake point of the machine and one attempt to unplug it with the PTO engaged. The hands and feet got injured by the rotor and the feeding chute, and also the injuries caused by the belt powering the thresher. Often the workers stand on unstable platform and in the event of a jerk or loss of balance the torso weight might push the hands and feet into the threshing drum. Also, the manual and power driven chaff cutters carry high accident risks when the workers attempt to feed the fodder into the rollers of the cutter. High incidences of chaff cutter injuries (including amputations of fingers and hands) have been recorded from the villages in southern India (i.e., 8.94 accidents/1,000 chaff cutters/yr) (Table 2). On the other hand, in the farmhouses in the northern India, the chaff cutters accidents accounted for 11%

of the total injuries²⁶⁾.

Responding to the public uproar of the thresher accidents, the government of India enacted the Dangerous Machines (Regulation) Act (1983), advocating compulsory installation of safe feeding chutes and feeding systems on the threshers. The safety requirements of the mechanical threshers have been specified in the standards (IS 9020, 9129 and 10618)³⁶⁻³⁸⁾, but many of the threshers used in the villages do not meet the safety requirements. The primary protection is to provide a master shield over the PTO stub shaft and also, the design optimization of the feeding chute is essential to keep it at the elbow level and the workers stand on a stable base. The placement of feeding chutes should allow the shorter people to reach the feeding area and the tall people have necessary clearance to avoid hitting the thresher.

Hazards of pesticide application

During the different stages of crop production, storage, packaging and transport, the pesticides are applied in the form of liquid sprays, mists, dusts, fogs, smokes, aerosol canisters and granules, thereby to protect crops from weeds, pests and diseases. The main function of pesticide spraying is to atomize the spray fluid into small droplets and eject the same to give uniform deposit of pesticide on the target. The sprayer equipment may be manual, tractor operated or power operated. The small sprayers are mostly hydraulic energy type manually operated sprayers, e.g., compression or lever operated knapsack sprayers, hand or foot operated bucket sprayer, rocking sprayer, duster and power knapsack sprayer. Nearly 5 million plant protection appliances are in use in rural India, of which about 3 million are lever operated knapsack sprayers. A typical lever-operated knapsack sprayer consists of a plastic or metallic tank of 10 to 20 liter capacity, a connecting hose with a lance, a nozzle and an operating lever (under-arm or over-arm type) for left hand operation. The tank has a pressure chamber and pump inside it or outside. Carrying on the back, the spraying is done at a frequency of 6 to 30 strokes/min. These sprayers are usually operated at a working pressure of 300 and 100 kPa for pesticide and herbicide applications, respectively.

The sprayer operators experience fatigue mainly due to carrying of the sprayer load as well as continuous lever operation³⁹⁾. The vibration arising out of powered sprayers also causes discomfort to the operator. Based on a survey of 5,340 knapsack sprayer users, Gite *et al.*⁴⁰⁾ noted that the pain and discomfort of the shoulder region have been reported by 62% of users, followed by back, left arm and other regions. Since 92% of the users were right handed, the majority desired that the force required in left-handed lever operation should

be reduced.

The pesticide applicators, mixers and loaders are at risk of exposure to toxic chemicals. It is not uncommon that the farmers broadcast pesticides or prepare pesticide solution with bare hands. Improper handling of pesticides, spraying without wearing personal protective equipment, oral poisoning of pesticides, etc. led to many sprayer related accidents (14.5 accidents/1,000 sprayers/yr) in the southern India (Table 2). The health and safety concerns demand institutional measures for comprehensive training on pesticide safety, dress code, emergency assistance in case of exposure. The implementation feasibility of precautionary measures requires to be examined, since it is a difficult behaviour to enforce in the tropical areas where protective wears add to the heat stress of the wearer.

Hand tool injuries and design changes

The hand tools vary widely in different regions owing to agro-ecological factors. The high rate of work, awkward work posture and design deficiencies of the hand tools result in cumulative musculo-skeletal strain and injuries in farm activities. Since the most hand tool injuries (e.g., cuts on the hands, feet and shins) have been classified as minor³⁰⁾, they often go unnoticed; however, their consequences are often painful and disabling because of delayed treatment. The AICRP data (Table 2) indicated that the overall incidence rate of hand tools related injuries varied from 0.02 (northern India) to 0.42 (southern India) per 1,000 hand tools/yr. Taking data from central India, Tiwari *et al.*³⁰⁾ reported the incidence rate for sickles as 0.16, followed by pickaxes as 0.09 per 1,000 tools/yr. The sickle related injuries mostly occurred while harvesting hard-stem crops like pigeonpea, chickpea, mustard and sorghum, and low-back injuries have been reported for pickaxes.

Studies have been carried out on the ergo-design improvement of hand tools, such as, spade/hoe^{9, 41)}, sickle^{18, 22)}, weeding tools¹⁷⁾. Pradhan *et al.*⁴¹⁾ carried out evaluation of two spades (hoes) with pace of work varied from 21 to 35 strokes/min for high-lift and 41 to 70 strokes/min for low lift work, and recommended a spade/hoe of about 2 kg weight having an angle of blade with the handle of 65 to 70°, the handle length of about 60 to 80 cm and a handle diameter of 4 cm. The need to look into the design requirements for farm tools for women has been emphasized^{42, 43)}.

Other Hazards and Injuries

Child accident

The children working or playing in familiar fields are

exposed to the hazards of farming, such as machinery, pesticides, fuels, noxious gases, airborne irritants, noise, vibration and zoonoses. Tiwari *et al.*³⁰⁾ reported that the primary agents of child (<14 yr) accidents in the farms are tractors and other machinery, livestock, building structures and falls. The AICRP data (Table 2) indicated that the children sustained about 2 to 5% injuries (southern, northern and central India), with 10% injuries reported from the villages in eastern India. These data were in contrast to observations from northern India²⁵⁾, where the children sustained 17% of total farm injuries.

Manual materials handling

The farmers frequently get involved in manual materials handling tasks, associated with manuring, harvesting of crops, grain storage, transportation, etc. In rural areas, loads weighing over 100 kg might be carried several miles on a daily basis. The women and children have to fetch water and fuel wood from a distance. The modes of load carrying include carrying on the head, on the hips, on the back and on the shoulder (yoke), with substantial risk of musculo-skeletal strains, including spinal injuries⁴⁴⁾. In general, the optimization of loads that may be lifted or carried would help in minimizing the potential risks. Comparing different modes of load carrying, Sen and Nag⁴⁵⁾ suggested that load carrying using transverse yoke was relatively less strenuous than the head pack and frontal yoke.

Snakebites

Snakebite accidents are common when the farmers work in open fields, threshing yards, barns, irrigation work and storage sheds, particularly during night work. In incidence rate of *other accident* category (Table 2) that varied from 0.23 (central India) to 1.12 (eastern India) per 1,000 workers/yr, the snakebites are the primary factors of concern. Special hats and foot wear that are capable of deflecting snakes should be worn in locations where there would be trees, shrubs, crop plants, etc. Non-availability of emergency accessibility of medical assistance in case of snakebites might be attributed to the higher fatality rate in the rural areas.

Falls and falling objects, and other hazards

The farmers are exposed to potential injury from slips and falls from slippery and uneven surfaces, unguarded roofs and raised platforms, tipping over objects or being pushed by a moving object, climbing ladders, silos, tractors, etc. During loading or unloading, collapse of unsecured stacked foodstuffs and overhead materials often causes injury. The probability of fall injury increases dramatically when the

Table 3. Work analysis in traditional and mechanized farming, using multi-method ergonomics review technique (MMERT)*

Factors	Work stressors related to hand tools, manual/animal drawn machine operations	Work stressors in mechanized farming, related to tractor and tractor implements
1	<i>Technical aspect</i> —design incompatibility and risk potential of hand tools and manually operated machinery.	<i>Working conditions and environmental aspects</i> —climate, machine vibration and noise.
2	<i>Working conditions and environmental aspects</i> —climatic stressors and strenuousness of work.	<i>Mechanistic aspect</i> —MMH tasks, targeted pace and volume of work.
3	<i>Mechanistic aspect</i> —MMH tasks and work volume.	<i>Technical aspect</i> —design incompatibility in the machinery.
4	<i>Biological aspect</i> —drudgery, musculo-skeletal strains and accidents.	<i>Perceptual and motor aspects</i> —constraints of machinery visibility and maintenance.

*: adapted from Nag and Nag⁵³.

fall height is more than 2 m and that impact forces reduce many folds if the victim falls on soft earth, hay or sand⁴⁶). In rural areas where the wells are not constructed with parapet walls, accidents happen in large numbers due to fall and drowning in wells, or fall of stones on workers while working in wells, etc. Therefore, protection against falls may include such measures that are realistic for the cluttered farm environment.

The use of electricity in rural areas with overhead electrical lines is a common sight. There are also transformers and distribution points located in some fields. In case of some electrical fault, the farmers go directly to such transformers and fiddle it to check/repair the fault. The electrocution accidents are common in such cases. Accidents also happen because of touching of irrigation pipes to overhead lines inadvertently⁴⁷). During handling and transportation of agricultural products, such as hay, straw, vegetables, grains and feeds, the farmers are at risk of respiratory disorders, due to exposure to dusts, gases, toxic chemicals, fungal spores and endotoxins. The lung disorders, such as farmer's lung, green tobacco sickness, organic dust toxic syndrome, bronchitis and airway obstruction have been reported^{48, 49}). In the open-field farming, the solar heat particularly in the summer months is a health hazard and can be life-threatening. The farmers must be well-informed of recognizing the heat stress and disorders, and immediate remedial measures⁵⁰). The change in the work timings and schedule, and optimized work-rest ratio might avoid high heat load. However, these measures depend upon the situation, and there is a need for information about the task, the people, human adaptability, and the environment.

Ergonomics Policy Intervention

The inclement work environment, drudgery, accidents and

injuries are the natural hazards to every one live, play and work in the farm environment. With the cognizance that the micro- and macro-ergonomics manifestations would vary with the resource poor and green revolution agricultural bases, geographic and agro-climatic variations, the ergonomics promises to reap benefit to the farmers and rural communities as a discipline of practicality⁵¹). Despite the promises in improving work systems and form of cultivation, the progress in ergonomics policy intervention in organizing work, redesigning the tools and machinery, and promoting safe and productive work practices has been slow^{47, 52}). To a large degree, this has been due to the lack of adequate address and analytical approach in exploiting the ideas. Since the agriculture has its unorganized character, the work systems analysis and design⁵³) requires a convenient framework to profile the aspects of work in traditional and mechanized farming, prioritize man-machine functions, and form guidance in improving work and working conditions (for example, Table 3).

Particularly in the traditional farming, there are concerns related to drudgery, slow pace of work, and other issues of work organization (e.g., primitive tools and methods), where ergonomics might bring solution by contributing to the work efficiency and productivity justified factors. For example, re-designed pedal threshers, wheel hoe weeder and multi-row seeders can be seen as replacement of age-old methods. The ergo-design refinement will compensate for the initial negation that the devices impose high physiological load should not be implemented. On the other hand, there are situations where ergo-design alternatives might be perceptible in terms of health and comfort. One such case is vibration severity among the tractor operators⁵⁴) and to reduce transmission of harmful vibration to the human body and minimize discomfort, e.g., damping of vibration of the tractor seat and power tiller^{14, 55}).

However, the complexity of redesign efforts in tools and methods of work must be realized to decide on its implementation. The whole gamut of hand tools have primarily been designed for right handed persons. Since nearly 8% of the farmers are left hand dominant⁽⁴⁰⁾, these users are unaware of any difference that might make for right and left handed operation. One might look into the dimensional incompatibility of the machinery or workplaces, in which answers are easy to incorporate taking account of the user population. There might be questions that require complex judgment as regard the extent of force one should apply to operate a machine or a quantity of load one should handle on a regular basis. As mentioned above, the braking force required for tractor operation (600 N or more) may be highly fatiguing to a person weighing 50 to 60 kg. Even a single axle power tiller generates many times more horsepower than a person can generate to hold the machine and walk-behind. Often the rear end of the power tiller gets lifted and the operator meets with severe accident.

The machinery (e.g., threshers and chaff cutters) accidents were often the result of human manipulative errors due to its design-induced limitations. For example, the poor feeding systems and workplace arrangements were responsible for majority of the mutilating hand injuries at the mechanical threshers^(35, 56). It recognizes the importance of the need solving approach and the level of technology applied is immaterial to address problems in the rural sector⁽⁵¹⁾. Retrofitting of safety gadgets on 100 chaff cutters (e.g., warning roller on the feeding chute; gear cover, blade guard) and 25 threshers in northern India⁽²⁶⁾ received a favourable response among the farmers.

In spite of the enactment for installation of safe feeding systems on mechanical threshers, as large as 41.85 accidents/1,000 threshers/yr in southern India (Table 2) brings out the shortcomings in production, distribution and monitoring the conditions of machinery in field use. The machinery introduced in the rural areas has not been well supported for maintenance and services by building up of local technical capability. Moreover, adhering to safety and design standards in constructing the manually operated and animal drawn implements is impractical to those fabricated in the local workshops or by the local artisans. The obvious limitations exist in enforcing legislation in farm activities except by making known of the hazards and educating farmers on safe work practices^(38, 57, 58).

There is an implied challenge for effective ergonomics transfer, since the poor farmers have a constant fear in endangering themselves to a newer approach which has not been time tested. However, the ergonomics job design

approaches^(53, 59) can be integrated and tailored in the line of ILO proposed occupational safety and health (OSH) management system⁽⁶⁰⁾, by organizational enabling of the local infra-structure, such as block development, rural agricultural extension services, and primary health services, to permeate ergonomics and OSH in the farming sector.

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